
AC 2011-911: WORK IN PROGRESS: INCORPORATING PERVASIVE COMPUTING CONCEPTS INTO AN AIRCRAFT MAINTENANCE JOB TASK CARD SYSTEM

Timothy D. Ropp, Purdue University, West Lafayette IN

Tim Ropp is Assistant Professor of Aeronautical Engineering technology at Purdue University. His research area is in operational safety risk management and NextGen technology innovations in aircraft maintenance. He has over 18 years experience in front line operations management and educational program development in risk-sensitive industries including aviation, emergency medical services, pharmaceutical and U.S. Navy and defense contractor operations. He is an FAA certificated aircraft mechanic with Airframe and Powerplant ratings, and a private pilot. Tim leads the AT Department's Hangar of the Future Research Laboratory, a multi-disciplinary lab focused on technology and process innovations for air vehicle maintenance, aligning with U.S. Next Generation Air Transportation System philosophy of embedded safety risk management and human-in-the-loop technologies. He currently teaches a highly interactive senior level maintenance management capstone course, Aircraft Airworthiness Assurance (AT402), utilizing Purdue's large transport aircraft, incorporating SMS and QMS principles, engaging his students through active learning challenges and applied research projects.

Dr. David M Whittinghill, Purdue University, West Lafayette

Raymond A. Hansen, Purdue University

Erin E. Bowen, Purdue University

Dr. Erin Bowen is an Assistant Professor of Industrial Technology at Purdue University. Dr. Bowen's research areas include aviation psychology, human performance and safety in aviation and high-consequence industries, and team performance. In addition, she provides training and education in the application of advanced statistical techniques to organizational settings. Dr. Bowen is founder of the interdisciplinary Applied Human Factors Research Laboratory at Purdue, focused on bringing expertise from psychology, aviation, and other industries to understand and improve the human component of high consequence and high technology organizations. Dr. Bowen holds a Ph.D. in Industrial/Organizational Psychology from Saint Louis University, with a graduate minor in Research Methodology.

Joshua L. Holmes

Work-in-Progress: Incorporating pervasive computing concepts into an aircraft maintenance job task card system

Abstract

In response to increased capacity and demand requirements of global air transportation predicted by 2025, the current U.S. air transportation system is being modernized by the implementation of the Next Generation Air Transportation System (NextGen). This overhaul and modernization effort links aircraft, air traffic controllers and airports through advanced satellite assisted computer networks and technologies. Modern aircraft themselves are being manufactured with these technologies built in, including computer networked systems and self-diagnostic capabilities to facilitate their own maintenance. These new capabilities place tremendous pressure on maintenance organizations to improve their process efficiencies, technical competence and capability, and overall speed in order to match those of the “smart” aircraft on which they will work. Traditional computerized networks and information management systems used by modern aircraft Maintenance, Repair and Overhaul (MRO) operations are believed to be insufficient for helping maintenance engineering technicians reliably connect with these advanced aircraft systems and obtain the highly technical data supporting them. But industry changes slowly and has many generations of workers with varying technology comfort levels and expertise. Students - the emerging leaders who will face these challenges - must be prepared to face and solve these technology integration problems. Students at Purdue University from aeronautical engineering technology, computer and information technology, computer graphics technology and industrial technology curriculums are practicing their skills at innovating upon existing technology and networked systems, integrating their “smart” tooling and network designs into an existing aircraft maintenance and engineering technology curriculum laboratory, while pursuing design results that can transfer to industry. Through hands on research and action learning experiences geared toward creating a user friendly paperless workspace, learners within the aeronautical engineering technology curriculum are teaming up with computer information and computer graphics student teams and faculty to develop and test enhanced computing tools for modernizing and controlling processes for the aircraft maintenance industry.

This report covers research and development of one such project in progress by a cross-disciplinary team of faculty and student researchers, who are developing a network-enabled, user-friendly electronic job task card management system for aircraft maintenance technicians. They are using the aviation department’s large Boeing 727 laboratory aircraft. It describes to-date development and testing of a pervasive, contextually-based data delivery approach for aircraft technicians that is expected to be faster and more capable than traditional electronic data file access. It includes development of electronic aircraft job task cards linked to a dedicated server, use of tablet PCs with touch screen technology for graphics enhanced job task instructions, including development of lightweight 3D graphics and other graphics-based process visualization capabilities delivered to the point of maintenance. Project goals are reduced overall time on task, reduced technician information search time and improved situational awareness. Testing will be accomplished on a large, non-flying transport category aircraft similar to those in industry.

Introduction

Under the Next Generation Air Transportation System (NextGen), the FAA is pursuing a congressional mandate that by 2025 all aircraft and airports in controlled U.S. airspace be connected to advanced, satellite-based networks and new technologies that continually share information in real time, resulting in improved efficiency and safety.^{1,2} Modern aircraft rolling off production lines today already contain NextGen navigation and self-diagnostic technologies, linked by computer networked system architectures that have capabilities to not only fly the aircraft, but self-diagnose and prioritize maintenance problems in the air and forward information ahead to maintenance facilities.

Modern maintenance operations run the risk of falling behind the technology curve to provide the level of precision maintenance required by today's advanced aircraft. Given the historically slow nature of technology integration and cultural change within the aircraft maintenance industry, students entering the workforce having experienced the process of technology innovation and engineering a networked system through a hands-on curriculum experience are better positioned to hit the ground running to address current industry challenges. If a learner is able to grapple with the issues of developing and deploying online technical data systems, performing valuable research as they do it, they will emerge much better prepared to face an industry that is in an unprecedented evolutionary state of advancement of technical support, communication and linked data systems.

A collaborative team of student and faculty researchers from the Departments of Aviation Technology, Computer and Information Technology, Computer Graphics Technology and Industrial Technology are developing a more user friendly, network-enabled process visualization and electronic aircraft job task card management system as one method of inculcating the modern philosophy of the pervasive computerized and sensor-embedded work environment into the students' repertoire of critical industry skills. Working within the Aviation Department's Hangar of the Future Research Laboratory at Purdue University, students are challenged to innovate upon the use of common personal computing devices and data networks used in aircraft maintenance, creating more intuitive electronic performance support to aircraft technicians.

As part of semester projects, students within a senior capstone course AT 402 Aircraft Airworthiness Assurance are assigned hands on, design-build-test projects relating to smarter processes, smarter tools and smarter networks for aircraft maintenance. They must reach out and work collaboratively with other students and instructors to experience first hand the challenges of developing a user friendly, network enabled technical work environment that requires their innovative solutions to ensure security, real time process visualization, communication and intuitive user interface requirements.

Hangar of the Future Research Laboratory

The Hangar of the Future (HOTF) lab is a collaborative workspace within the Department of Aviation Technology used for both individual project and collaborative course design-build-test projects for modernizing aircraft maintenance. Student and faculty researchers are encouraged

to extend problem solving solutions beyond their core skill and knowledge areas, pursuing novel solutions to technical and process problems related to 21st century air vehicle maintenance encountered by industry. The lab's philosophy aligns with the U.S. Next Generation Air Transportation System (NextGen) philosophies^{1,2} with specific attention on enabling enhanced data network architectures that provide more real time, contextually relevant data to the human being. The sophistication of modern aircraft is such that they are, in essence, autonomous, flying computer networks. The lab promotes innovative solutions for visualizing and controlling maintenance on these highly-advanced machines. Using a blend of existing technologies (Radio Frequency Identification, Optical 2D barcode and 3D Augmented Reality for example) for parts locating and installation, and the aviation department's large laboratory aircraft as learning and research platforms, students and faculty work to integrate these into standard equipment and tooling to create human-in-the-loop *Smart Networks*, *Smart Tools* and *Smart Processes* that sustain safety, quality and reliability outcomes. Researchers are designing a networked electronic job task card management system for aircraft maintenance similar to those already used by industry, incorporating the novel technologies described. To complete this test system, they are also developing a test set of electronic aircraft job task cards with enhanced data delivery capabilities. This system is being constructed to provide easily accessed, contextually relevant and highly visual technical data to the technician directly at the aircraft. This includes "smart" job task cards that support light weight 3D graphics and task assistance and adjust to the level of the technician's expertise. This system is being constructed to support multiple client platforms using a variety of personal computing devices.

Background

Electronic job task cards are rapidly evolving into use in the aircraft maintenance industry. Their architectures are often part of a larger data management component used in Product Life Cycle Management (PLM) enterprise systems. These have traditionally been used to integrate services within manufacturing and production environments, to monitor and control work flow processes. Electronic job task cards represent a key component impacting workflow control. While set up to serve the needs of the data system however, they often fall short of providing the human operator on the front line with the intuitive access and relevant data delivery to the point of maintenance where tasks are performed. The needs and limits of many PLM style job card systems drive the technology, as the saying goes, to become the master instead of the servant.

As a result, despite the tremendous computerized capabilities of modern aircraft and existing electronic maintenance networks containing aircraft technical manuals and diagrams, many maintenance job tasks are still largely accomplished and tracked using manual methods such as job task "signoff" on paper-based task instructions.³ The same report noted visits to two Maintenance Repair and Overhaul organizations and a major U.S. Air Carrier component overhaul facility in 2009, revealing planning, work distribution and documentation of job tasks were often still accomplished using traditional paper-based job task management systems. Product Data Management systems of various sorts are not new. Computerized aircraft data and computer workstations are currently used by the aircraft maintenance industry to deliver technical aircraft data to front line technicians. However in aircraft maintenance operations, this information has been observed to be largely delivered in linear pdf or similar formats that can still required scrolling pages of text. Thus, the human's time consuming data searches are

simply shifted from sifting through paper to scrolling pages of electronic text and the problem remains. While electronic signoff and networked maintenance data capabilities currently exist within the aircraft maintenance industry in various forms^{4,5}, they are neither widespread nor standardized.

The aircraft technician often must contextualize and sift through a myriad of technical information when completing a maintenance task on the aircraft. To facilitate aircraft maintenance job tasks, a technician may print and carry a variety of diagrams from a maintenance manual related to a component on which they are working, despite having electronic image access on computers. Additionally, computer workstations may be several feet removed from the proximal aircraft work area, requiring a technician to physically leave that area when further information is required or when additional help is needed. These frequent departures potentially compromise situational awareness during critical maintenance tasks. Interesting nuances in the way traditional networks and computers are used in the aircraft maintenance repair and overhaul (MRO) and manufacturing industry have been observed. Even when using two dimensional electronic displays on laptops, technicians have been observed to resort to paper-based manuals during some troubleshooting tasks, due to context limitations of scrolling electronic pdf files, cgm or raster images. This has been observed to result in extended search times (reviewing other manufacturer or in-house engineering data) as well as physical hunting on the aircraft itself.⁶

Technicians have even been observed to print a two dimensional component diagram and physically invert, twist and skew it to try to match what they think they are looking at on the aircraft. As noted by Woo et., al.⁶ many of these documents can contain multi-page spreads of complex system components, thus leading to multiple documents needed during a technical maintenance task on an aircraft. This introduces further distraction from the maintenance task at hand and presents additional risk of loss of situational awareness and helpful contextual information when switching between diagram pages. As demonstrated in small scale tests, an enhanced electronic job task manager that delivers more visually driven, user-commanded or controlled detail as needed at the point of maintenance (like the ability to view a 3D image if needed) can help improve overall task speed, and preserves context, and situational awareness for a technician in certain circumstances.⁷

Designing a networked job task card system test bed

The student research team began design and development of a basic computer network as well as an enhanced electronic job task card to test within the network in Fall 2010. The goal was to stand up a functioning computer network with a dedicated server and access points, and use the HOTF lab's wireless tablet computers to accomplish real maintenance tasks on the department's Boeing 727 operational but non-flying laboratory aircraft. Thus the test bed "system" was to be comprised of both functional network and job task cards operating within it to experiment with creative new data display concepts.

Designing the business intelligence architecture

A previously created process map of an industry aircraft Maintenance, Repair and Overhaul maintenance cycle was studied. The map allowed visualization of a typical large aircraft maintenance process from arrival at the facility until the aircraft is released back into service. Places in the process where networked personal computing devices could be utilized, or provide near real time fact based information to technicians were identified and key data sources for those points listed. A rough business intelligence relational database architecture was created, listing data source requirements in parent-child relationships. Those relationships specific to supporting a technician's electronic job task card were the primary areas of focus, and formed the nexus of the ongoing network development on this project.

Based on cloud computing philosophy, the emerging system utilizes a service-oriented architecture, a conceptual approach used in software engineering that envisions applications as loosely joined assemblies of modular components. The challenge put to the student team was to create simple and standardized interface definitions in which individual services are easy to build, modify, reuse and recombine. Subsequent applications could be created and maintained more quickly, at a lower cost than traditional network systems, and adapt more flexibly to changing business requirements. By breaking up the system into smaller functional components, the team has sought to deliver near real-time maintenance process intelligence and support to front line technicians and production supervisors with fact-based decision-support information.

Designing the network

Functional network design point requirements included:

- ability to access electronic data via a web interface
- allow for instant updates and real-time communication across the domain
- allow for dynamic reorganization of cards and content
- accommodate a tablet PC based system
- allow for future design of Drag-n-Drop capabilities from a supervisor's master control touch screen computer
- allow on-demand information retrieval

These requirements were based on conceptual wireless network design, covering an aircraft technician's work environment that included a large transport category aircraft on an airport ramp (Figure 1). This was also the basis of the current physical network construction (Figure 2).

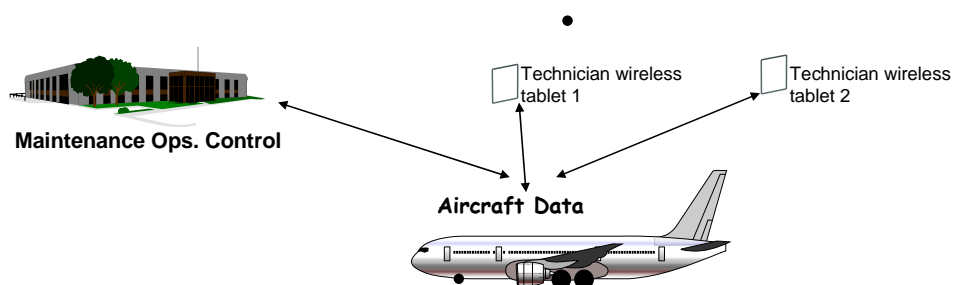


Figure 1. Conceptual wireless network design

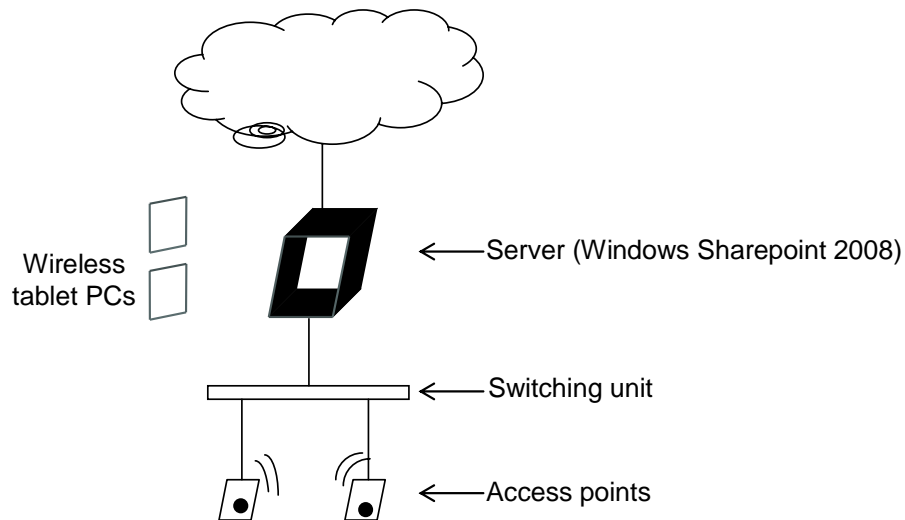


Figure 2. Current physical network design

Due to cost and time constraints, this phase of the project adhered to requirements of using OTS software and existing hardware components on hand. A wireless infrastructure was developed to use wireless touch tablet PCs. The proposed testing scenario would allow students acting as technicians to work around the aircraft, access technical diagrams and sign off the electronic job task cards assigned. The wireless infrastructure was setup using two wireless Cisco 1232 APs connected back to a 24 port Cisco switch, which that was connected to the LAN. Optimal placement of the access points were identified based on a signal strength evaluation. One AP was placed on an interior hangar wall near a window, with a patch antenna outside pointed at the airplane which sits on an outdoor ramp. Another AP was placed inside with an omni antenna hanging down to give 360 coverage into the hangar as well.

The student team opted to explore the use of SharePoint 2010 standard version and a Microsoft Windows 2008 Server. Aircraft maintenance job task steps were input using SharePoint workflows, allowing creation of discrete steps for each job task card. Additionally a maintenance operations “manager” (in this case the instructor of the laboratory) would be able to assign job task cards wirelessly to designated student “technicians” at the aircraft via the network.

Designing an electronic job task card format

After review of electronic support data for technicians and electronic task cards, the concept for enhancing an electronic job task card into a more supportive information source was brainstormed. The need for layered levels of detail was discussed in terms of varying technical skill levels that can exist among a work crew. Novice technicians may require great detail for a given task, whereas a veteran would require less. This layered approach was coined as Layered Adaptive Aircraft Task Support. The concept was adapted from similar Artificial Intelligence concepts used for information and task prioritization and semantic web technologies for knowledge sharing^{8,9} and the FAA’s NextGen security framework described in the U.S. Joint Planning and Development Office’s NextGen security concept termed *layered adaptive security* designed for airports.¹⁰ The FAA’s system is a risk-informed security system using multiple

technologies, policies, or procedures adaptively scaled and arranged to defeat a given level of threat. This concept was identified as very pertinent to the nature of maintenance performed on aircraft which can be influenced by organizational factors or error producing situations that can blend into operations and if unrecognized, can cause accidents or delay.

The ability to deliver layered, user-commanded detail as needed at the point of maintenance (for example, requesting a 3D image of a wing tip fairing being installed for better contextualization), was believed to be one step to help preserve situational awareness and improve overall task efficiency. This resulted in the decision to develop both a “standard” electronic flat screen view job task card using the Sharepoint development tool, and a 3D job task card to compare the utility and limitations of both.

The student design team identified four aircraft maintenance job tasks on a large transport category aircraft. These were identified from OEM maintenance planning documents for the aviation department’s Boeing 727 laboratory aircraft, a non-flying aircraft with fully functioning engines and systems used in the learning and research laboratories. Normally these learning laboratories utilize paper-based job task cards very similar to the industry. For a baseline, a paper based version of all four job task cards would be developed. Three of the job task cards would be converted into an electronic version using Sharepoint, and one would be created using more advanced 3D software providing a more highly visual, graphics-based job task card.

A process map of each job task was created, identifying and visualizing steps in the task process where, once these were constructed into an actual job task card, a technician would require additional visual data or instructions that would normally require accessing a separate maintenance manual. An example is shown in Figure 3 below.

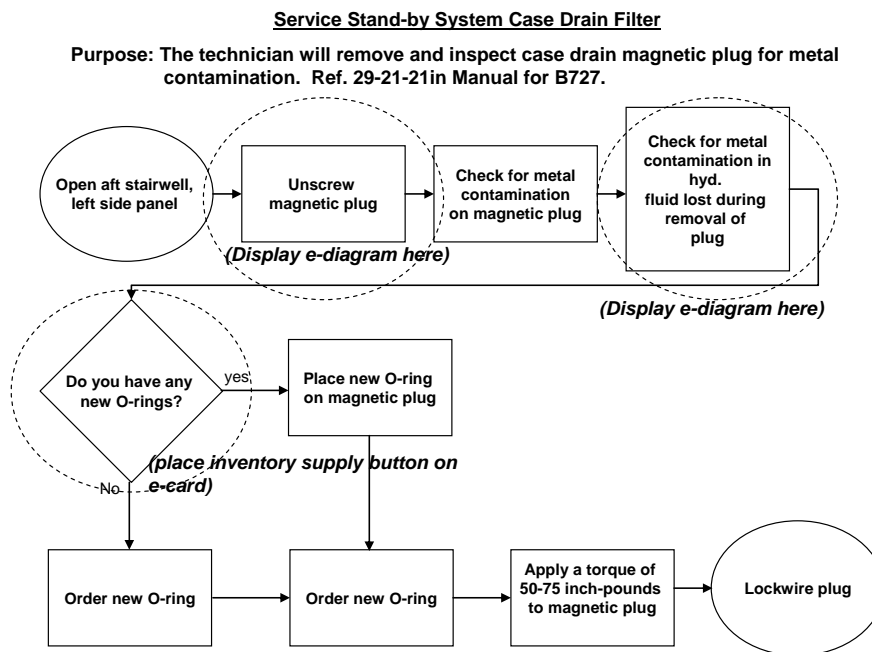


Figure 3. Job task process map with data display requirements circled

From these maps, printable, paper-based job task cards to be used by other student “technicians” were created in Excel (Figure 4) for use in future comparison tests against an electronic version. Prior to conversion into electronic format, the paper-based cards were evaluated by Aeronautical Engineering Technology faculty who instruct on the large aircraft and have aircraft maintenance industry experience. The task cards were further validated by the student design team, who worked through each job task card and verified the tasks could be completed.

INSTRUCTIONS		SQUAWKS
1	1A Standby Hydraulic System Case Drain Filter Inspection/Check	
	1A1 Keep ground lockpins and wheel chocks in place. Tag out APU operation and Hydraulic System operation.	
		Inspected (Lead):
	1A2 Open aft stairwell left panel (Refer to Figure 201). Make sure that you have a 5-gallon bucket on hand in case any hydraulic fluid is leaked.	
	Completed (Tech):	Inspected (Lead):
	1A3 Unscrew magnetic plug.	
	Completed (Tech):	Inspected (Lead):
	1A4 Check for metal contamination on the magnetic plug.	
	Completed (Tech):	Inspected (Lead):
	1A5 Check for metal contamination in the hydraulic fluid lost during removal of the plug.	
	Completed (Tech):	Inspected (Lead):
	1A6 Place a new or the same O-ring on the magnetic plug. Ask for instructor assistance for this step.	
	Completed (Tech):	Inspected (Lead):

Figure 4. Paper-based aircraft job task card

Once the test job task cards were validated, they were then developed into a beta electronic version, incorporating check box sign offs and other visual data displays (Figure 5).

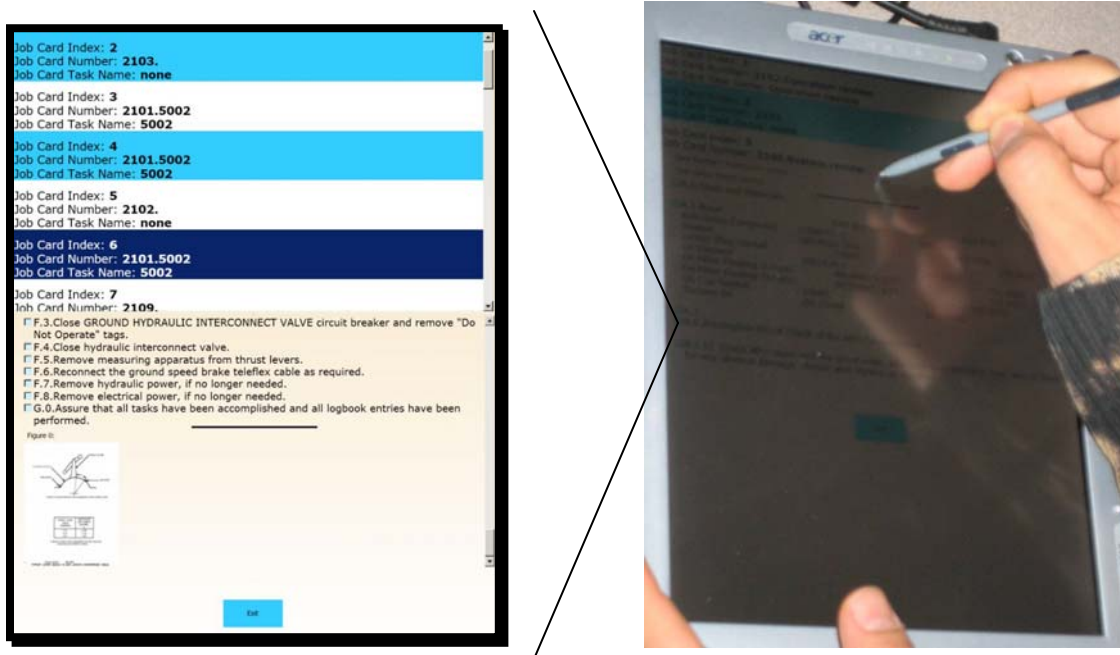


Figure 5. Beta version electronic job task card developed for a tablet PC

The HOTF group then partnered with students from Computer Graphics Technology, producing a realistic 3D rendering of the B727 left wing tip fairing. The CGT group developed an electronic 3D graphics-based removal/ inspection task card (Figure 6).

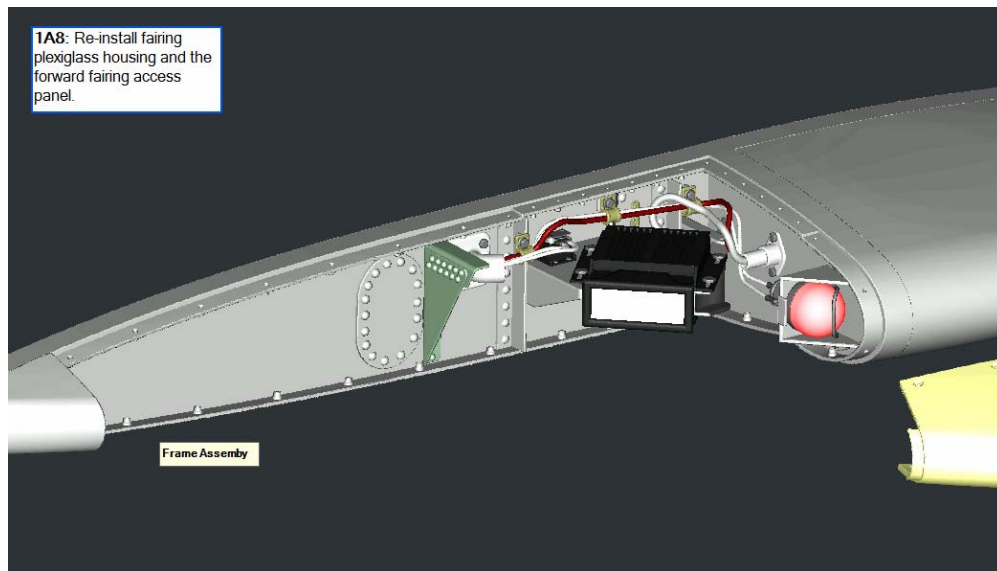


Figure 6. Sample 3D wingtip fairing removal/inspection online job task card

Discussion

Early system functional tests of the electronic job task card system were conducted in December 2010. The computer network design which the team stood up demonstrated basic functional

capabilities, but requires further refinement and construction to make it operate in a more user friendly manner. The network tended to “freeze up” with large graphics files and was sometimes difficult for a student user to intuitively access; it was stated by users that access and “starting” the e-cards was still too complex for someone who had not been in on its development. However, the electronic system demonstrated the ability to deliver more visual and contextually relevant data to the student technician at the ‘point-of-maintenance’ than traditional paper-based schemes used in the learning laboratories. Refinement and testing of the network and electronic job task card system is ongoing. This includes continued integration into an actual curriculum laboratory (AT 402), in which paper-based lab aircraft maintenance tasks have been extensively used in the past. Early feedback from student users indicated they were able to acclimate to the online system with only a few minutes introduction. Maintenance tasks using the test job task cards were performed successfully using just a table PC.

Outcomes sought for the networked computing system being developed within the airframe laboratory are to enhance the curriculum and student experience by establishing a true to life networked aircraft maintenance environment. This in turn develops a natural research platform closely resembling operations in the industry, including common knowledge, skill, ability and IT solution gaps associated with large aircraft maintenance. It is believed that students will be able to think in more innovative terms when they help develop and are able to work directly with more pervasive, user-friendly computing systems as a part of their routine laboratory learning experience.

This has already resulted in more in depth use of computers and networks by students within the large aircraft lab. Students incorporate systems thinking and a networked environment into problem solving considerations. They speak in terms of “levels of risk”, “process streamlining” and “quality” while using computers as leveraging networked tools to help accomplish these. They also tend to use more industry based terminology consistent with current NextGen initiatives. This simulates more realistically the domain of technologies they will experience in the industry and enhances the curriculum’s applicability. As this networked system is developed and continues to be integrated into the learning laboratory, measures of positive impact will be assessed that include:

1. Increased 'wrench time' (productive work) at point of maintenance.
2. Reduced queuing and searching for tools, parts and technical information.
3. Reduced overall time-on-task.
4. Reduced skill gaps between novice and veteran technicians.
5. Increased real time process visibility impacting front line awareness and decision making.

At this writing, the student research team is preparing to deploy and perform larger scale comparison tests of the job task card system transforming more paper-based laboratory job task cards into “smart” user friendly online task cards described here. The research team discovered that networked, on-demand use of 3D images raised further challenges such as transferring complex diagrams from large native CAD files into lightweight images that could be easily sent. As a result, early testing on the 3D job task card was relegated to loading onto a tablet’s hard drive and testing the human performance using a 3D graphics based task card. Future R&D plans include improving 3D graphics delivery and adding “layered” user-supporting information

such as online video tutorials, safety hazard reporting and other visual displays. Early system operational testing and very rudimentary user testing began in December 2010 on the Microsoft Sharepoint platform and HP tablet computers. Development and testing are ongoing.

Conclusion

Technology advances on aircraft and unyielding safety and reliability demands for air transportation have placed tremendous pressure on aircraft maintenance organizations. To capitalize on the tremendous efficiency capabilities of modern “smart aircraft”, maintenance operators must return an aircraft to service sooner, which means the technician must be equipped to problem solve and troubleshoot with greater finesse at the side of the aircraft and in the moment. To do this requires innovation beyond many networked and computerized data support systems currently used in aircraft maintenance. One area of particular importance is the increasing use of computers to deliver online electronic job task cards for accomplishing and signing off maintenance tasks performed by the individual. Students must come to an appreciation of the rigor and infrastructure required to build and sustain such a “smart system”. Integrating these systems into the learning laboratory as part of the curriculum but also as part of course research projects in and of themselves is one way to positively introduce students to the new world of pervasive computing in industry. Although it is still very early in development and testing stages, early system testing demonstrated that more relevant information can be distributed to a student technician providing greater task visualization and control of a maintenance process.

The dynamic and risk-sensitive aircraft maintenance environment requires the clearest information and fact based decision making by individuals. Safety and airworthiness depend upon the human being accurately carrying out tasks, identifying and resolving problems. Clear, pertinent data that is easily and rapidly accessible using a variety of electronic platforms is essential if rapid cycle times, safety and airworthiness requirements are to be maintained in this age of the networked, electronic aircraft. Students who can experience this in a controlled, learning environment are better prepared to work with industry teams and pursue innovative solutions to problems as tomorrow’s leaders in a dramatically evolving industry.

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