Advancements in Canadian Forces T56 Engine Interactive Electronic Technical Manuals (IETM)

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ABSTRACT

An ageing aircraft, reductions in personnel numbers and experience, long training cycles, and a continued high operational tempo are putting tremendous stress on the ability to maintain and operate the Canadian Forces (CF) CC-130 fleet. These demands have highlighted the need to improve how the aircraft will be supported into the future.

Coincidentally, developments in technology are providing a number of potential new "tools" and new approaches to meet the CC-130 requirements. The Internet, video games, adaptive analysis techniques, and novel information management capabilities are all contributing to a new way of using, finding, and storing information.

In support of the CC-130 fleet, a number of these new technology "tools" are being introduced to provide enhanced training, diagnostics, planning, maintenance, and information management, but they are mainly

isolated and separate from each other. The challenge and effort is to bring all these "tools" together into a fully integrated, comprehensive package that provides a single front-end interface to most effectively embrace and use all the necessary information to get the job done anywhere on the globe.

This paper will show how and why the initiatives currently underway by the Directorate of Aerospace Equipment Program Management (Transport & Helicopters) (DAEPM(TH)) and Canadian industry will take advantage of existing and emerging technology to provide a total, all-inclusive information support system now and into the future. As part of the realization of this goal, efforts have focussed on the next evolution of Interactive Electronic Technical Manuals (IETM) for the CC-130 that merges technology solutions such as 3D Knowledge Object models and a Case-Based Reasoning Tool, in order to address the challenges described above.

1.0 INTRODUCTION

Originally written in a format that only supported paper publishing, the CF CC-130 technical manuals have evolved into an interactive web-based application. The advent of Standardized General Markup Language (SGML) authored publications has allowed for efficiencies in document revision and has improved the speed at which changes can be issued. Updates to the technical manuals can now be delivered over the Defence Wide Area Network (DWAN), allowing for revisions without having to print and distribute numerous paper copies.

The progression to an electronic version of the technical manual provides improved access to information. An entire library of information can now be installed onto a laptop, making it available wherever a maintenance task is being performed. In addition, the electronic format of the IETM allows the technician to efficiently navigate sections, tables, figures, wiring diagrams, with the added capability to search for required information. This advancement has allowed for capabilities not possible with paper versions such as: key word search, vector-based graphics, wire tracing, and active linking between content.

Although far ahead of traditional paper or "page turner" publications, the current IETM is not without its limitations and inadequacies. The vision of the Advanced IETM program is to introduce additional functionality into the current IETM that will help resolve current shortcomings as well as mitigate the affects of reduced personnel and experience levels while simultaneously increasing aircraft availability. The advanced features, tools, and technologies will allow field level technicians to perform their job functions more efficiently and effectively.

This aim of this paper is to describe the initiatives of DAEPM(TH) and Canadian Industry using existing technology to provide a total, all-inclusive information support system for the CC-130 by focussing on the next evolution of Interactive Electronic Technical Manuals (IETM). The paper will show how the IETM advancments will merge technology solutions such as 3D Knowledge Object models, dynamic simulations, and a Case-Based Reasoning Tool in order to address the CC-130 support challenges.

2.0 BACKGROUND

The CF is facing a number of challenges:

2.1 Technology

Technology is moving faster than most of us can keep up with. However, today almost everyone has some grasp of using computers. Graphics, Modelling, Simulation, and Analytical software have incredible capabilities; while hardware is becoming smaller and more powerful, capable of multi-purpose tasking and connection from anywhere, anytime. Technology has advanced to a point that many off-the-shelf applications already exist which could provide significant improvements to the existing technical information systems.

2.2 Personnel

The CF has a serious personnel experience and training situation on its hands. It is currently facing a loss of experienced and trained personnel due to retirements, staff reductions and limited recruiting in the 1990s. A move to a more generalized "jack-of-all-trades" approach has created a high training cost in both time and resources. At the same time the CF is introducing a number of new aircraft fleets all with the same personnel, which places further demands on people. In addition there are fewer experienced personnel to conduct the training and a new generation of recruits that may prefer not to learn the traditional way. The proliferation of the Internet has changed how the younger generation accesses information and how they learn. This generation is accustomed to learning by doing. Learning needs to be intuitive and presented in a medium familiar to the student. Efforts need to be directed at mitigating these personnel issues.

2.3 Operational

The CF continues to adjust to changing and increasing operational needs. The high operational tempo of the CC-130 fleet keeps it stretched to the limit in support of both overseas and domestic operations. The CC-130 is being tasked to go anywhere in the world, anytime, and at a moment's notice. Extended deployments to austere and remote locations are now the "norm". The cost of deployed operations (logistics, etc.) continues to rise. Although communication with deployed sites is expanding, bandwidth still remains restrictive. This higher operational tempo demands a faster response rate from supporting information systems.

3.0 THE RESPONSE – AN ADVANCED IETM

In order to respond to these challenges, advanced features are being introduced into the CC-130 IETM. The goal is to implement off-the-shelf technologies that help solve current operational & support issues. The advanced IETM needs to capitalize on technology in order to capture experience, reduce learning times, and integrate virtual information from flight line to contractor. Eventually, it will be fully integrated into a one-stop technical & logistics support and training system. The envisioned future system will include, as a minimum:

- Single Portal & Consistent User Interface
- Comprehensive Electronic Technical Data Repository
- On-Line, Adaptive Training
- Interactive 3D Models / Videos built-in
- Logistics Support (Sparing / Parts Tracking / Config. Control)
- Enhanced Troubleshooting / Diagnostics

- Fleet Management Optimization and Prognostics Tools
- Life Cycle Analysis (Cost / Availability, etc.)
- Portability
- Links to CF-wide Enterprise support systems

3.1 Prioritization of Effort

A logical approach was used to focus developmental efforts. The objective was to use a data-driven methodology in order to clearly prioritize areas or components of significance. Thus the results would direct developmental efforts on resolving actual and important maintenance issues. Three main approaches were used:

- Known problem areas identified from reliability and historical data;
- Data-mining of maintenance records; and
- User feedback from experienced field technicians.

Based on this data analysis, the T-56 engine was selected for the initial Advanced IETM developments. Methods and results are summarized below.

3.1.1 Known Problem Areas

A review of reliability data identified high maintenance drivers. For example, the engine accessories display a high rate of No Fault Found indicating there was actually nothing wrong with those components returned for overhaul. (See Figure 1 below). This points to a need for better technician understanding of the system and a requirement for better troubleshooting procedures.

Accessory	NFF Rate
Paralleling Valve	75%
Fuel Enrichment Shutoff Valve	75%
Speed Sensitive Valve	65%
Speed Sensitive Control	55%
Temp Datum Valve	41%
Coordinator Control	33%

Figure 1 – No Fault Found Data T56 Engine Accessories

3.1.2 Data-mining

The use of Data-mining was aimed at isolating the main contributors to aircraft downtime, mission abort rate, and person hours. An analysis of available maintenance data and records was performed based on the following criteria:

- Cost (represented by person hours to complete the maintenance)
- Frequency (# call-outs per 1000 flying hrs)
- Complexity (high, medium, low)

- A/C Downtime (hours)
- Number of High Priority Supply Parts Requests (IORs)
- No Fault Found (NFF) Rates
- Engine Removal Rates
- Time to Train (high, medium, low)
- Safety Criticality (high, medium, low)

The following figure provides a sample of data analysis performed for the CC-130.

A/C	Description	Person Hours (Maint. Record Totals)	Frequency (per 1000 flying hrs)	Complexity	A/C Downtime (hours)	# of IOR's	NFF Rate (Field)	NFF Rate (Depot)	Removal Rate (freq. of occurrence)	Time to Train	Safety Criticality	A/C Downtime Rank
Modules	Power Section	30401.4	18.60	High	300.10	-	25%	14%	37%	Medium	High	1
	Compressor	396.6	0.48	Medium	31.19	-	48%	N/A	4%	Medium	High	9
	Comb Section	195.1	0.12	Medium	28.73	-	14%	N/A	0%	Medium	High	10
	Turbine	1050.7	0.55	High	100.61	-	26%	N/A	0%	Medium	High	2
	RGB	893.4	1.00	High	27.04	-	21%	N/A	7%	Medium	High	12
	RGB	20418.1	4.93	High	54.95	-	43%	27%	36%	Medium	High	4
	Torquemeter	438.2	2.10	Medium	17.21	-	80%	24%	1%	Low	Medium	15
Accessories	Fuel Pump Assy	1048.4	0.68	Medium	26.86	-	11%	40%	74%	Medium	Medium	13
	Paralleling Valve	511.6	0.73	Medium	38.11	-	0%	75%	85%	Medium	Medium	7
	Fuel Control	5749.5	3.47	High	41.76	3	5%	N/A	59%	High	High	5
	Fuel Enrichment Shutoff Valve	556.6	0.53	Medium	28.41	-	3%	75%	93%	Medium	Medium	11
	Temp Datum Valve	6192.9	10.08	Medium	13.93	2	4%	41%	33%	Medium	Medium	16
	Speed Sensitive Control	970.6	1.50	Medium	8.81	-	4%	55%	90%	High	Medium	18
	Speed Sensitive Valve	437.9	0.64	Medium	10.66	-	3%	65%	83%	Medium	Medium	17
	Coordinator Control	1316.2	1.44	Medium	92.37	-	4%	33%	58%	High	High	3
	Propeller Aircraft - Variable Pitch	51177.2	35.03	Medium	35.96	5	26%	N/A	40%	High	High	8
Prop	Housing Assy - Valve, Prop Control	13521.2	11.06	High	22.02	4	3%	N/A	64%	High	High	14
	Housing Assy - Pump	2723.4	2.23	High	38.42	4	3%	N/A	41%	High	High	6

Figure 2 – T56 Engine Maintenance Data-mining Results

From these results, it became apparent which systems created the greatest concerns and thus should be addressed first. The large number of T56 engine accessories that showed up from the data-mining also reiterated the need to better identify and rectify accessory faults. Therefore, they became the focus of the initial developments into improved troubleshooting methods.

3.1.3 User Feedback

Some of the shortcomings of the current IETM were identified through user working groups. Common themes throughout the working groups noted that the IETM should provide:

- Better visual references. This could include 3D animations, or something as simple as including a short video of a procedure or photo of a part or part condition, for example a photo demonstrating visual inspection criteria.
- Improved ease and speed of navigation and searches. They indicated that at times it is difficult to locate information that is relevant to the fault. For some tasks they found that the information was not well organized and was located in several different sections of the IETM.
- A system hierarchy approach to locating information. This would include, or link to Cautions/Warnings, Maintenance Procedures, Parts Lists, Training, Visuals, and Tooling. They felt that this would also provide a good starting point to locate information and would show how parts are linked to other components.
- Troubleshooting starting points and enhancements. They felt that one of the biggest issues with troubleshooting for an inexperienced technician is the inability to identify a starting point. This is particularly true for systems that are fairly complex such as accessories or wiring.
- Have the same types of simulations that were available during their training. Providing them the ability to change the state of controls, visual flows, see the implication of an embedded fault, show the interaction of the electrical and mechanical components, etc. Basically provide them a better understanding of how a complex system operates.

4.0 INITIAL ADVANCED FEATURES

As described above, the development of advanced features for the CC-130 IETM will initially address issues identified as known problems or through the data-mining research and user feedback. The selection of initial developments areas is also driven by the availability of existing technology solutions to resolve these issues. The initial development areas can be categorized into four main groups: navigation, web-based enhancements, troubleshooting aids, and modelling. Each of these will be described in detail in the following sections.

4.1 Navigation (System View)

Currently, CF technical data is organized on a numbering system mainly according to the level of maintenance and type of maintenance activity involved. A much more intuitive approach would be based on the aircraft “system”. The system view will allow one to select the technical manual by drilling down from the aircraft to the specific system or component one is interested in, such as the engine turbine, and find links to all technical data related to that system in one location instead of in several different manuals such as first-line maintenance in one manual, third line in another and the parts list somewhere else where you need to know the CF Technical Order (CFTO) reference number to find anything. The following figures demonstrate the system view approach. Simply by selecting the appropriate component either from the list or the graphic, the technician can locate all relevant information on the component with links to procedures, inspections, and parts information.

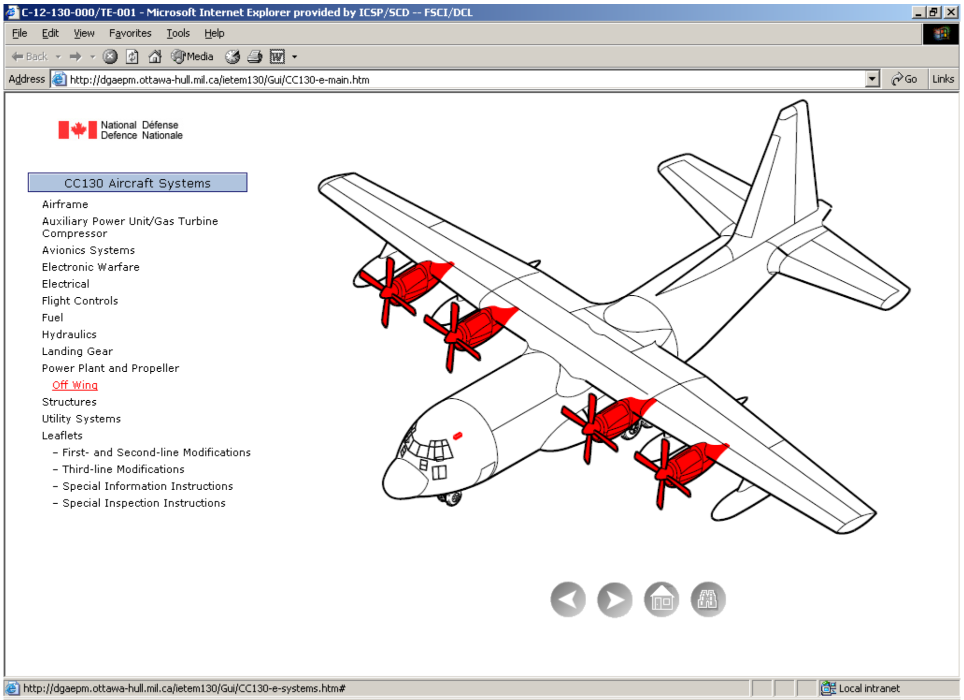

Figure 3 – Aircraft Level System View Highlighting T56 Engines

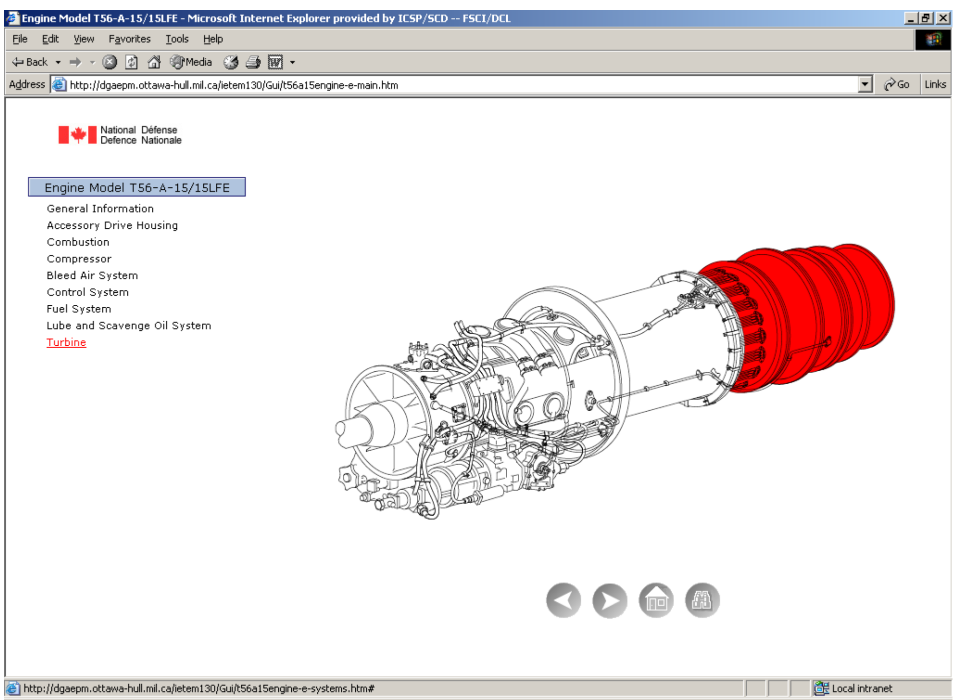

Figure 4 – Component Level System View – Highlighting Turbine

4.2 Web-Based Enhancements

A number of web-type features are being incorporated into the IETM. These will permit a more internet-like feel to the IETM, bringing them in-line with common internet practices, which are familiar to most technicians and becoming an expectation in current computer usage. Improved search engines are being introduced to provide the ability to do state-of-the-art Internet style searches within the IETM. Bookmarking will be made available to allow users to place individualized notes and tags in the IETM that allows them to quickly and easily return to that spot. Additionally, the concept of tailoring the IETM to the individual user, or contextualization, is being developed. The idea of contextualization is to filter or personalize the IETM content that a user sees. This can be applied in the following ways:

- Skill Contextualization: Customized presentation of content to support technicians of varying experience. A user's profile or run-time preference can determine how content is displayed and the level of interaction required with IETMs.
- Configuration Contextualization: Product configuration filtering to support multiple models and variants of a single product. In the field, technicians could access aircraft specific information by entering the tail number.
- Task Contextualization: This is the ability of the IETM to highlight specific types of tasks for special attention by personnel. In this way, it is possible to link a user and his/her qualifications to the task he/she may be required to perform. As well, it is possible to flag critical tasks to the attention of the user.

4.3 Troubleshooting

The analysis of troubleshooting data showed that faults in the engine control system are especially difficult for technicians to diagnose. In other words, needless maintenance is being performed driving up costs. The configuration of the T56 engine control system, combined with low experience levels in the CF and the lack of clear troubleshooting guidance makes the engine accessory system the top candidate for development of improved troubleshooting methods. In addition, CF expertise is scattered across the several units making it difficult to migrate or share this experience across the entire fleet. Finally as the fleet continues to age, failure modes will change; therefore, the troubleshooting procedures cannot remain static. Consequently, an improved troubleshooting method must address these concerns. A case-based reasoning program called SpotLight® developed by CaseBank Technologies Inc. was selected as the core of the improved procedure. It is a dynamic system that will utilize both existing knowledge and records as well as incorporate new faults and their solutions to the data set resulting in a continually learning system that will grow with time.

4.3.1 Case Based Reasoning

Case-based reasoning allows the technician to focus on the highest probability solutions through past knowledge and a reasoning algorithm to interact with the user to link optimum solutions to faults. However, it will also learn as it goes to apply new solutions as they appear, thus capturing and preserving problem-solving knowledge. The SpotLight® program has been successfully integrated into a trial version of the IETM for nine engine accessories such as the fuel control and paralleling valve. A thorough data-set was built from existing troubleshooting guides, historical records, subject matter expert inputs, and hundreds of known solutions (approximately 280 solutions for 33 symptoms). In SpotLight®, through a series of questions and information windows, the technician is led through to the most likely cause of the problem and shown the corrective action to rectify it. As each troubleshooting session is saved it can be recalled later to further build the solution set and retain that knowledge for future reference. The accessory troubleshooting package will form part of a field trial being conducted in the fall of 2008. Figure 5 below shows an example solutions screen from the case-based reasoning package.

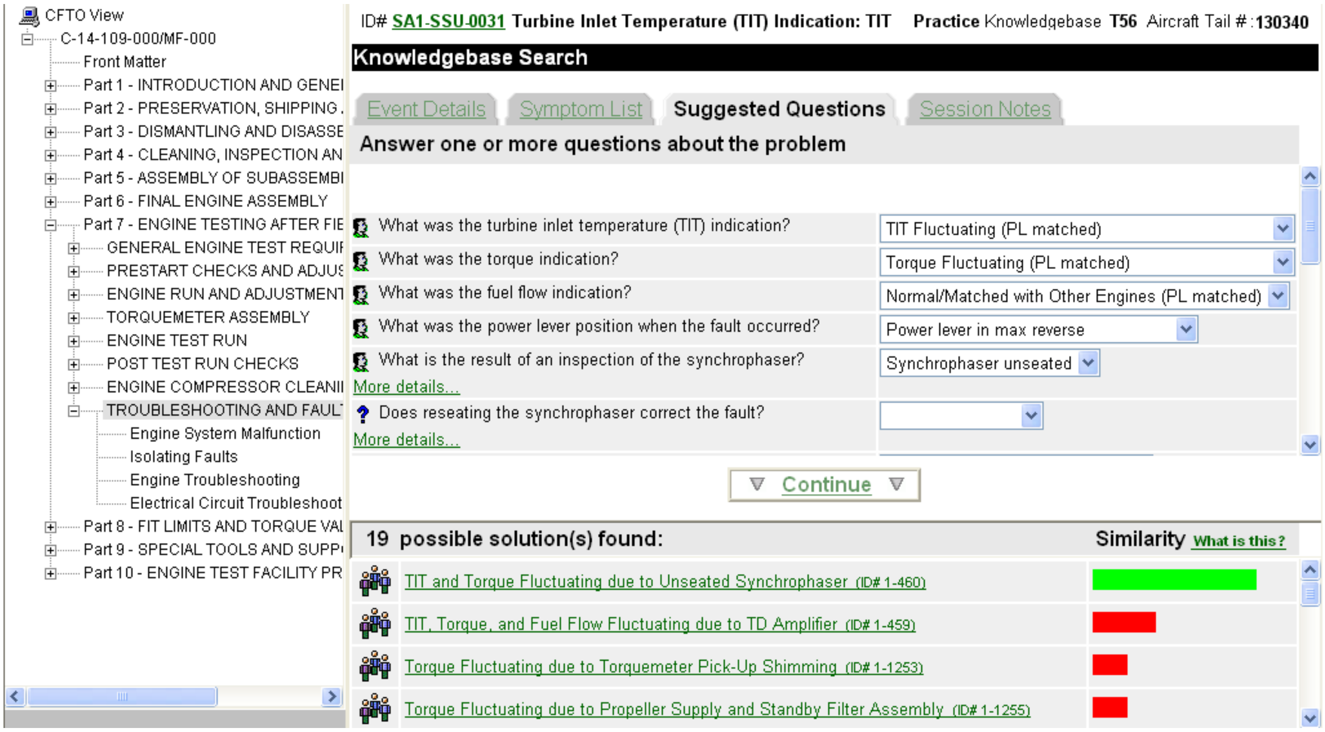

Figure 5 – Case Based Reasoning Example Solution Screen

4.3.2 Wiring Diagram Enhancements

In addition to identifying engine accessories as a high priority target for improved troubleshooting procedures, feedback from users also showed that there is a shortage of expertise and experience in resolving wiring snags. Even though the current IETM allows for wire tracing and highlighting, technicians often do not know where to start and cannot match the schematics/diagrams to the actual parts/locations on the aircraft. In response, a simple to follow wiring troubleshooting appendix is being prepared that will guide an in-experienced technician through standard electrical troubleshooting sequences. An additional easy to incorporate feature will be the insertion of graphics/photographs of the actual aircraft location and/or component linked to its position in the wiring diagram. Refer to Figure 6 for a sample wiring diagram with an embedded image.

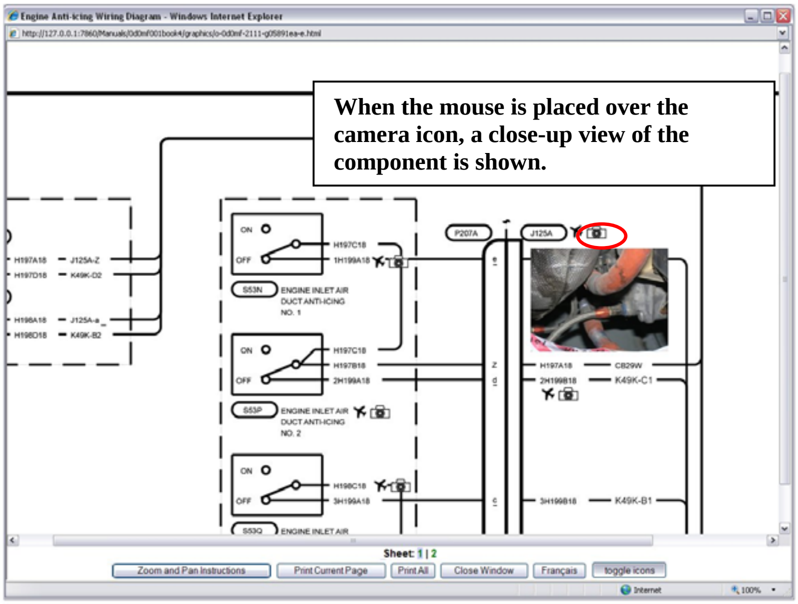

Figure 6 - Wiring Diagram with Embedded Photo

4.4 Modelling

Better visualization and representation of systems and components was clearly identified as a potentially major improvement to the IETM. By providing technicians with a visual representation or model, not only of the engine and its components, but also of system functionality and relevant maintenance procedures, the IETM would bridge a significant knowledge gap and provide the visual link from IETM to actual component. Three modelling techniques were pursued: 3-D modelling of the engine, animation of maintenance procedures, and interactive, dynamic system mock-ups.

4.4.1 3-D Models

Using NGRAIN Canada Corp. technologies, 3-D models of the engine and components were created. NGRAIN models were selected for use because they are not merely visual representations; they are more accurately called “3-Dimensional Knowledge Objects” (3KO). They can contain embedded data and links, be broken into sub-components down to the smallest nuts and bolts, and be manipulated in several manners including dynamic animations. Below are the 3KO’s of the T56-A15 engine and a context view of selected internal components.

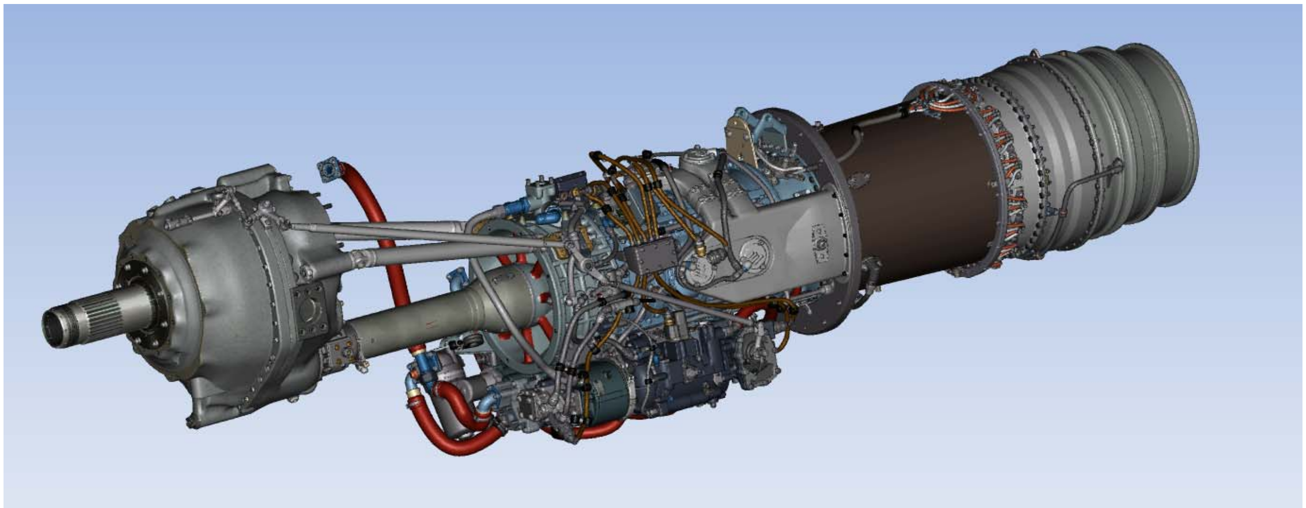

Figure 7 – 3KO of T56-A15

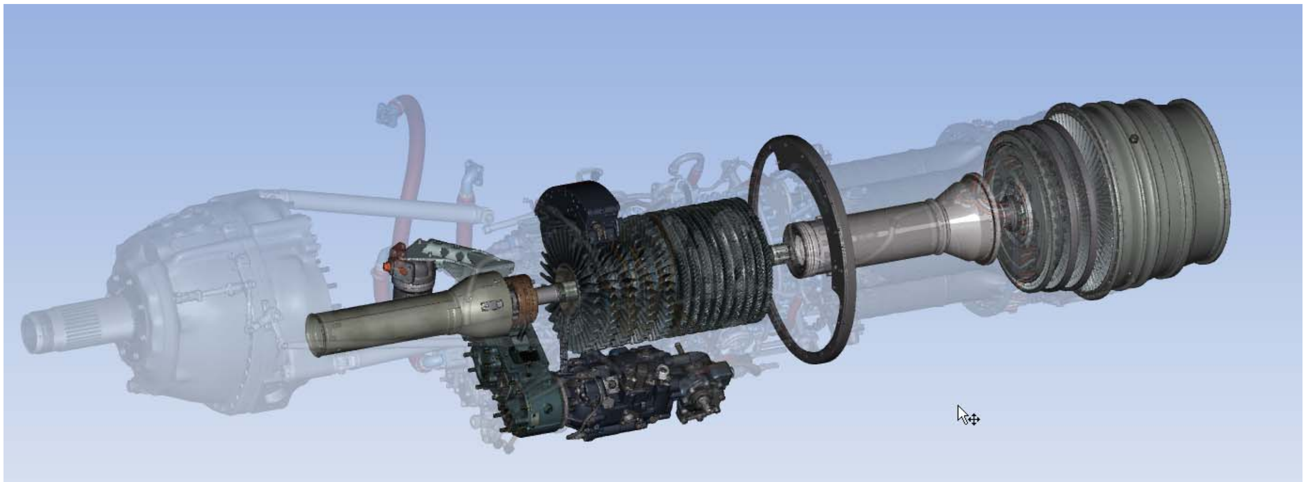

Figure 8 – Context View of T56-A15

The 3KO's have already shown tremendous potential to enhance IETM capabilities. They are not only an immediate accurate view of the engine or component, but they can also be moved, manipulated, or taken apart to see exactly how and where selected components fit into the overall engine. Initial demonstrations have shown that inexperienced technicians become familiar with the equipment much faster using the KO models than with other methods. The 3KO's radically changed how technicians look for information about components. They now go straight to the models.

In addition to storing information and being able to be manipulated, the NGRAIN models also form the basis for animations of selected maintenance procedures. Especially suited to assembly and disassembly of components, the animations, visually and with implanted text, take the technicians through the actual maintenance procedures found in the technical manual. Thus the animations using the 3KO provide a realtime demonstration of procedures without turning a wrench.

4.4.2 Dynamic Simulations

Finally the use of dynamic system simulations developed by Simgraph Inc. will be migrated from the training world into the IETM making them part of the actual technical manual. This will permit technicians to interactively review system functionality not only in the classroom but also on the front line. The Simgraph simulations have so far only been developed for select systems from which the greatest benefit will accrue. An example screen shot of a simulated fuel system is found below at figure 9.

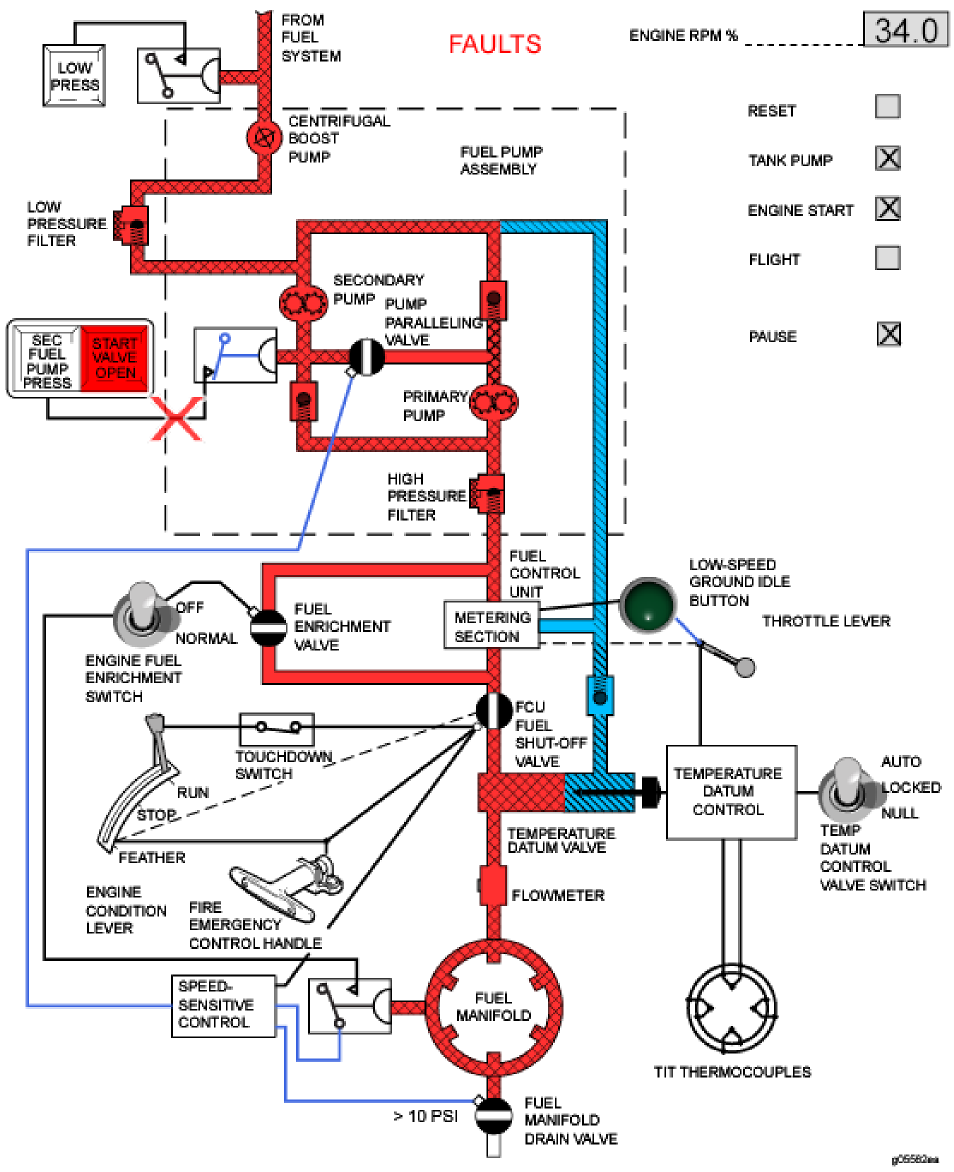

Figure 9 – Simgraph Simulated T56 Fuel System Operation

5.0 TRAINING IMPACT

Obviously, the advanced tools being introduced into the IETM will have a significant impact on the training of CC-130 technicians. The IETM now becomes both Maintenance & Training Manual providing a common, consistent source for both training and operations. It enables technicians to “train like you fight and fight like you train”. Information content and accuracy is controlled through the established content management system and standard publications processes, so it is always up-to-date and accurate. Technicians can use the IETM for all their information requirements. Training can be done continuously including all aspects: Basic, Advanced, Refresher, and Just-in-Time. For example, the use of Simgraph dynamic simulations is already part of the training curriculum for CC-130 technicians; now it will be available anywhere, anytime as an integral part of the IETM. A trial using NGRAIN 3KO models and animations at the CF School of Aerospace Technology and Engineering (CFSATE) on the CC-130 propeller system concluded that the students learned 60% faster and retained more knowledge over more traditional book-based methods. As training is a fundamental requirement of the CF, this will be a tremendous benefit for the CC-130 fleet.

6.0 LESSONS LEARNED

Initial lessons learned include:

- Integration is vital. Technicians want to go only to a single source/system for everything.
- Visualization is easier and quicker to grasp than pure text.
- Easy navigation and search capabilities are expected features in an advanced IETM
- Models become initial reference (“go to” place for technicians).
- Procedural and Parts List publications verification and validation should be done using models and animations.

In the validation process, several types of errors, that had previously gone undetected or unreported, showed up very clearly in the 3KO model animations. In fact, errors were found immediately using the procedures. For example, the following showed up during development of the animated procedures:

- Missing steps in the procedures from written vs. performed maintenance practice.
- Incorrect assembly sequences from written vs. performed.
- Steps indicated installation of hardware not present in the engine model.
- Hardware shown attached to the wrong location.
- Instructions were repeated to remove parts when they have already been removed
- Parts Nomenclature (difference between the Parts List and the Maintenance Manual) needed to be corrected and made consistent
- Parts quantity - difference between actual and specified
- Incorrect orientation of the parts shown during assembly. The parts are sometimes indicated going in the wrong way e.g. bolts.

7.0 CURRENT ACTIVITIES

7.1 Prototype evaluation / trial

A critical part of the IETM development is user feedback and validation. As part of the evaluation of the initial cadre of advanced features, a trial is being conducted at a CF CC-130 field maintenance unit to determine to utility/value of each of the advanced features. The trial includes the assessment of: wiring enhancements and guide, 3KO model and animations, selected dynamic simulations, and engine accessory case-based reasoning troubleshooting. The trial is being conducted in two ways:

- Side-by-Side: to compare effectiveness of Adv. IETM for "un-trained" technician vs. fully trained experienced technicians using current references.
- Longer-term: to fully evaluate all features of the IETM to determine pros and cons and any adjustments needed to make the features more useful.

Trial results will show where it makes sense to implement the advanced features as well as where and what additional features should be developed next. An implementation plan will be built on the trial results.

7.2 Integration

Work is also underway to integrate those 3KO models and those procedures that have been validated. Although included in the above trial, the inclusion of certain models and select procedures has already been given the go ahead for implementation. These features will soon be part of the working IETM available to all CC-130 technicians. The processes for inclusion of these advanced features are being thoroughly documented to ensure adherence to airworthiness and quality requirements of the CF. Once established, the processes will then be applied as other advanced features become ready to fully incorporate into the IETM. A roadmap is also being developed that lays out a 5-10 year concept for continued development of the CC-130 IETM. This will clearly establish the IETM vision for the CF CC-130 fleet.

8.0 CONCLUSIONS

In summary, we can conclude:

- An advanced IETM can be developed using existing technologies and COTS products;
- Development efforts need to focus on actual and significant issues identified through objective data analysis;
- Technologies must be integrated – one-stop, accessible to all personnel, and linked to other CF information systems;
- Developments need to be validated in phases through feedback & trials prior to implementation or identification of further investments; and
- An advanced IETM provides a powerful training tool and link from training to maintenance operations.
- The IETM will form the basis for future information systems development for the CC-130.