The CF-18 Integrated Maintenance Training System - IMTS

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ABSTRACT

The Integrated Maintenance Training System (IMTS) is an F-18 Hornet maintenance simulator recently developed by Atlantis Systems International (ASI) and The Boeing Company for the Canadian Forces (CF) and Royal Australian Air Force (RAAF). The IMTS simulates all systems of the F-18 aircraft, including avionics, armament, fuel, environmental control system, propulsion, and flight controls. Students interact with the IMTS using a full-size replicated cockpit and two touch-sensitive "Smart" display panels. Over 400 different maintenance procedures and malfunctions are simulated, in addition to "freeplay" functionality, meaning that the simulator is expected to react like a real F-18 aircraft even when procedures are not followed exactly or the student does something unexpected. The IMTS requirements were driven by large upgrades to the F-18 avionics and weaponry for both countries. In Canada the F-18 upgrade is called the Incremental Modernization Program (IMP), while in Australia it is called the Hornet Upgrade (HUG).

In this paper, existing IMTS capabilities will be described, along with ideas for future enhancements and new capabilities made possible by the unique and flexible design of the IMTS software. The role of the IMTS within the Canadian F-18 fleet school will be examined along with early assessments of the utility and learning effectiveness of this new tool.

ABOUT THE AUTHORS

Gordon Coulman is the Training Support Officer at the Canadian Forces F-18 training school at Cold Lake, Alberta called 10 Field Technical Training Squadron. Mr. Coulman was also project manager for the IMTS program, working closely with the Hornet Modernization Project Office at National Defence Headquarters in Ottawa. His background is in aircraft operations, flight test engineering, and computer systems, databases, technical training, and project management. For the past four years, he has been working closely with Boeing and ASI on the design, construction, and acceptance testing of the IMTS.

Blake Melnick is Vice President and Chief Knowledge Officer at Atlantis Systems International. His background is in education and business with a specific emphasis on e-learning and the knowledge sciences - Knowledge management, knowledge mobilization and knowledge building. Prior to joining Atlantis, Blake served as Head of External Relations and Workplace Research for the Institute for Knowledge Innovation and Technology. Blake has spent the past 10 years providing expert advice to businesses and educational institutions around the world in the development and implementation of technology supported learning environments, training and professional development programs.

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INTRODUCTION

The purpose of the Integrated Maintenance Training System (IMTS) is to give students hands-on experience in F-18 testing and troubleshooting procedures in a safe and controlled environment. Apprentice technicians gain experience and learn how to follow technical orders using real-life aircraft malfunctions. Unlike the aircraft, apprentices can make mistakes without fatal or expensive consequences. Malfunctions and procedures that take hours or days to perform or repair using a real aircraft can be performed in minutes using the IMTS, then the system can be reset to give another student or team an opportunity.

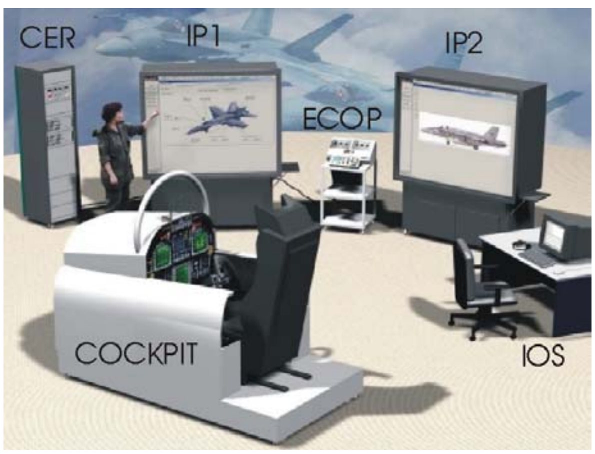

Figure 1. IMTS Components

Replicated Cockpit

Each IMTS has a simulated F-18 cockpit, complete with all switches, instruments, and displays. The cockpit also has a simulated ejection seat and canopy jettison handle, with removable ground safety pins and safe/arm handle. Instructors can ensure that students enter and egress the cockpit safely, while ensuring that all safety pins are in place. A detachable platform is placed at the same relative height as the F-18 leading edge extension (LEX), making it possible for students to learn where to step and what to hold on to while entering or leaving the cockpit.

Figure 2. IMTS Replicated Cockpit

Many cockpit controls use actual aircraft components for added realism and durability. The Digital Display Indicators (DDI) and Heads Up Display (HUD) are simulated using commercially available data projectors. The HUD image reflects from a mirror and specially coated transflective glass.

Simulated air to ground and intercom communications are provided via headsets for students and instructor. A software interface gives the instructor control of simulated ground-based navigation aids, tower frequencies, and secure communication channels.

Figure 3. IMTS Interactive Panels and Cockpit

Interactive Panels

Two interactive panels from Smart Technologies, Inc. are used to display aircraft images, maintenance panels, test equipment, sounds, and other information. The large (2m diagonal screen) interactive panels are touch-sensitive and interaction with virtual switches and controls is done by touch. Additional computers, laptops, or multimedia devices can be connected to the interactive panels via an external connection and an additional internal connection. These extra inputs make it easy to host guest lecturers or display digital lesson materials or aircraft technical orders during instructor-led training. The interactive panels also have an electronic whiteboard feature, with virtual "markers" and eraser.

Figure 4. IMTS Electrical Checkout Panel (ECOP)

Electrical Checkout Panel

An electrical checkout panel (ECOP - Fig 4) provides a simulated digital multimeter and two sets of actual aircraft cannon plugs (connectors). Simulated voltage and resistance measurements are taken using actual multimeter probes inserted into the connectors. Students gain experience using the pin numbering system on the plugs. Measurements of coaxial cables can be performed using an actual Time Domain Reflectometer (TDR), which is connected to the front of the ECOP. A switching device within the ECOP can substitute coaxial cables of varying lengths and serviceability depending on the requirements of the simulation logic.

Figure 5. Adjustable Podium and IOS

Instructor Operator Station

Instructors can interact with and control the simulation using the interactive panels or by using the Instructor Operator Station (IOS), which consists of a standard PC situated at a desk. A keyboard video mouse (KVM) switch permits access to other computers from this station without requiring additional monitors or keyboards.

Common Equipment Rack and UPS

Finally, the Common Equipment Rack (CER) is provided for simulation computers and power management. An Un-interruptible Power Supply (UPS) supplies 15 minutes of power and a graceful shutdown in the event of facility power failure.

OBJECTIVES

When is Training with a Real Aircraft or Simulator Appropriate? Which is more effective and efficient?

Maintenance procedures are ideally practiced on a real F-18 aircraft under typical flight line conditions, but using a real aircraft can present practical problems:

1. The noise of avionics cooling fans, ground power and hydraulic carts makes instruction very difficult;

2. The instructor/student ratio must be very low for safety reasons, typically from one to four students per instructor. This makes it expensive to train a large number of students in a reasonable time;

Procedure Name	IMTS Students	Aircraft Students
Chaff / Flare Functional Test	8	4
Engine run-up	8	1
Simulated engine fire	8	Not possible
Troubleshoot wire break	4	2
Average procedure	8	2

Table 1. Maximum Students per Instructor

3. Aircraft bookings can be difficult, given operational requirements and the reluctance of crew chiefs to risk breaking a serviceable aircraft by performing unnecessary maintenance procedures or disassembly;

Figure 6. Technicians Performing Engine Run-Up

4. A 0.5 hour F-18 engine run can cost $3000 CDN in fuel alone, not counting the wear and tear on the engine or the reduction of operating hours before the next inspection or overhaul;

5. It is not possible to easily simulate malfunctions using a real aircraft. Introducing failed components or wiring to a serviceable aircraft is counter-intuitive and may cause other expensive components to fail. Airworthiness or safety directives may prohibit using aircraft in this way; and

Procedure Name	IMTS Time	CF-18 Time
Chaff / Flare Functional Test	1 hour	8 hours
Engine run-up	0.25 hour	2.5 hours
Simulated engine fire	0.25 hour	Not possible
Troubleshoot wire break	1 hour	Min 4 hours
Average procedure	0.5 hour	4 hours

Table 2. Training Time – IMTS vs CF-18 Aircraft

6. Performing procedures on an aircraft takes a lot more time to set up and perform than using an IMTS. Aircraft procedures may require the following resources:

   - Test equipment
   - Tow crew and mule
   - Ground support equipment
   - Aircraft maintenance log entries
   - Consumable supplies and fluids
   - Specialist personnel for adjacent systems (ex: explosive cartridge removal)

Figure 7. CF-18 Aircraft used for Instruction

Acquisition and Operating Cost Discussion

The cost of IMTS can be compared to the cost of using a real aircraft for technical training, but this analysis does not give a true picture, since the training capabilities of IMTS greatly exceed those of an aircraft alone. Without IMTS, the CF would have no method of teaching realistic troubleshooting of the CF-18. The acquisition of additional CF-18 aircraft for technical training would not change this fundamental difference in capability.

At the CF training school in Cold Lake (10 FTTS), five IMTS have been installed. To provide a similar number of dedicated maintenance training aircraft would be completely out of the question because of the cost and infrastructure required.

The support costs (building space, consumables, security, and maintenance manpower) requirements to support an IMTS are significantly less than the cost of maintaining a non-flying CF-18 aircraft.

ADVANTAGES AND EFFICIENCIES OF IMTS

1. **System Integration**. The IMTS replicates the function of every major system of the F-18 aircraft. Interactions between these systems are simulated via simulated Mission Computer (MC) logic, simulated MUX Bus, and Maintenance Status Display and Recording System (MSDRS). This high level of integration means that the IMTS reacts to stimulus almost exactly like a real F-18.

2. **Free Play**. The IMTS is not a procedural trainer. The simulation is robust and has sufficient depth such that maintenance actions and control inputs do not have to be entered in any particular order. The IMTS reacts like an F-18 aircraft.

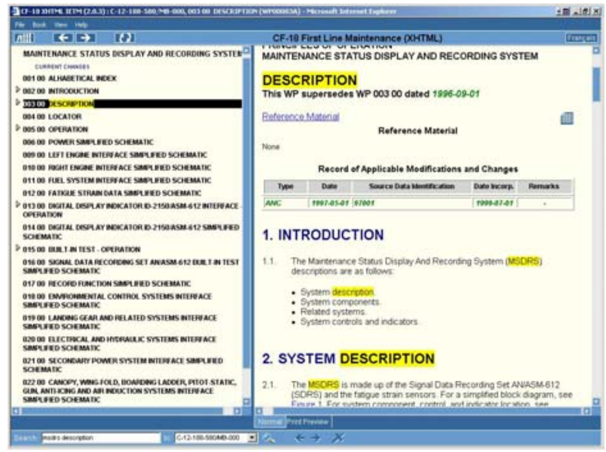

Figure 8. CF Interactive Electronic Technical Manual

3. **Multi Purpose**. The IMTS has two large interactive panels that are not only used for displaying the IMTS simulation; they are also ideal for the display of a wide variety of instructor-led training materials. The IMTS can display PowerPoint, Technical Manuals, videos, or any other digital media. The XML-based technical manuals used by the CF interact perfectly with the touch-screens.

Fig 9. Virtual Cockpit Display

4. **Flexibility**. The IMTS can be used with or without the hardware cockpit. The instructor can demonstrate aircraft functions from the interactive panels or the cockpit. The virtual cockpit automatically reflects switch and display state changes from the hardware cockpit. Instruments and controls within the virtual cockpit can be sized as needed.

5. **Realism**. The IMTS hardware and virtual cockpits are very realistic and functional. All switches and displays are carefully reproduced, including the cockpit geometry, symbology, and surface finishes. In many cases, aircraft parts are used. The flight control system includes correct control feel and power actuated stick trim. The HUD uses an authentic combiner glass like the aircraft.

6. **Ease of Use**. Most instructors can learn the basics of operating the IMTS in about three hours. The student interface is simplified and requires less time to learn. Once instructors learn the basics, they need to practice the maintenance procedures they intend to use for instruction.

7. **Instructor Tools.** A large inventory of software tools are provided by the IMTS to the instructor:

   a. **Snapshot**. The IMTS can take a "snapshot" of its present state that can be restored at a later date. The purpose of this feature is to permit instructors to configure the IMTS for a particular lesson. Parameters include aircraft state, malfunctions active, aircraft panels, test equipment, and others. Snapshots can be stored on a central file server and recalled by any instructor on any IMTS.

Figure 10. Maintenance Shortcut Interface

   b. **Maintenance Shortcuts**. The IMTS has a maintenance shortcut screen to automate repetitive maintenance tasks. Instructors can enable or disable this screen depending upon learning objectives.

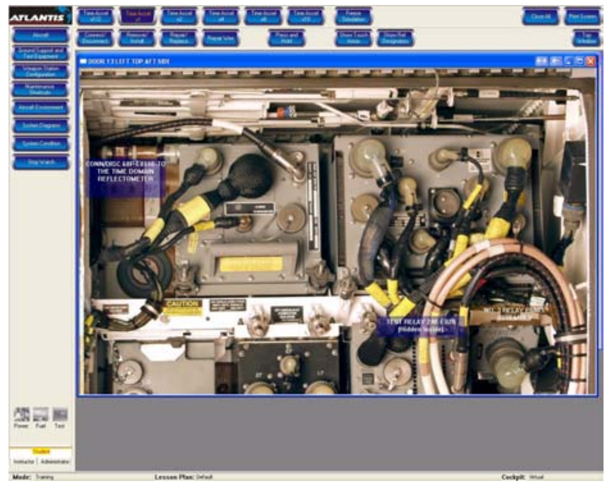

Figure 11. Maintenance Action Window

   c. **Video Tree**. Maintenance actions are performed by navigating around and inside the virtual aircraft by touching photos of aircraft maintenance panels. Once panels are open, switches and circuit breakers are activated by touching them. Command buttons are used to install/remove or connect/disconnect components and electrical connections. Controls are provided to highlight all available touch areas and component labels.

Figure 12. AN/APM-480 Transponder Test Set

d. **Test Equipment**. The IMTS has an extensive inventory of virtual aircraft Test Equipment (TE). TE is connected to the aircraft and operated via the touch screen. Realistic indications are displayed depending upon the simulation state. Test patterns and power-on BIT checks are realistically displayed.

Figure 13. Air Starter Control Panel

e. **Ground Support Equipment**. All GSE items are accurately displayed, with interactive controls and indications.

f. **System Diagrams**. The IMTS can display diagrams of aircraft systems, including block diagrams, schematics, and interactive diagrams such as Environmental Control System (ECS) valves. New (non-interactive) diagrams can be added by instructors as required.

Figure 14. 3D Flight Control Model

g. **3D Flight Control Model**. The 3D model displays all aircraft flight control surfaces. As the flight controls function in response to control inputs, the model accurately and instantly reflects the simulation state, including malfunctions such as a broken actuator.

h. **Drawing Tools**. The interactive panels include a tool set that instructors can use to "write" directly on the displays. Four virtual markers of different colors are provided, along with an eraser. Instructors can save or print completed notes and diagrams in a variety of formats, including a web page (html).

i. **User Manuals**. IMTS user manuals are available to both students and instructors in Adobe Acrobat (pdf) format from the interactive panels.

j. **Simulation Time Controls**. The simulation can be frozen, slowed down (1/2 speed), or sped up (up to 8X). This enables more effective instruction during rapid events and saves time during servicing tasks such as refueling. Stopwatches are provided for timed events.

k. **Sounds and Tones**. The IMTS presents environmental sounds as well as all aircraft voice alerts and tones. Engine sounds are carefully modeled.

l. **Malfunctions and Procedures**. Over 400 F-18 malfunctions and procedures are supported. Malfunctions can be queued and up to three can be active at once. Malfunctions have a wide range of difficulty for different training objectives.

APPROACHES TO TRAINING

Traditional Simulation Role with CBT Theory Lessons

In the past, the CF and RAAF used maintenance simulators purely to simulate operational procedures and malfunctions. The simulator was seen as a substitute for practical work on the aircraft, for reasons of aircraft availability, safety, and malfunction simulation. The simulators were used with groups of 2 to 4 students in a separate area from the classroom where theory, equipment location and function, interfacing, and other academics were instructed.

Figure 15. CF Legacy CBT Instruction

CF Use of Intensive CBT and Lessons Learned

Theory lessons were largely given using Computer-Based Training (CBT), originally using a system called Advanced Instructional System 2 (AIS-II) from McDonnell Douglas. As a result of feedback from operational fighter squadrons, students, and instructors, the CF determined that intensive CBT with a small fraction of hands-on practical exercise was not a very effective method of instruction. The primary reason for this assessment is the nature of the learners. The CF student population consists of adult tradesmen who are not self-directed learners and who respond better when working in facilitated teams using a varied approach to instruction combined with practical exercises. Most CBT training is of the "page turning" variety, which becomes boring after a very short time.

Re-design of the CF Training Curriculum

The CBT system was re-hosted to the PC platform in the mid 1990's, but no significant courseware changes occurred. Efforts began in earnest in 1999 to re-design the CF-18 curriculum and instructional techniques to reflect the new "blended" delivery objective. In 2003, Boeing was tasked with developing new blended courses to reflect the ECP-583 R1 aircraft configuration.

Applicability to Blended Learning / Mixed Delivery

Because of the multipurpose capabilities of IMTS, the CF have designed new courses and training environments to take full advantage of this potential for improved instruction. The new courses have a typical class size of eight students. The classroom space contains the IMTS at the front of the room, with an adjustable-height instructor podium that houses the IMTS instructor interface. The podium can be raised for use as a lectern, or lowered for use as a desk.

Figure 16. CF IMTS Blended Learning Classroom

Newly developed CF courses use a spectrum of instructional techniques depending upon the learning objectives, subject matter, and instructor preference.

Method	Purpose	Percent
Instructor Led IMTS Multimedia	Introduction, purpose, location, interfacing	35
Interactive Courseware (CBT)	Theory of operation, basic function	15
IMTS Simulation	Location, switches and displays, operation, procedures, testing and troubleshooting	35
F-18 Aircraft	Removal/installation, operational checkout procedures and functional tests, boresight, fluid handling	15
Total IMTS portion:		**70**

Table 3. Typical CF Instructional Delivery Mix

Aircrew use of IMTS

CF aircrew also use the maintenance simulators. Because the IMTS has a highly detailed cockpit, it is ideal for learning switch location and function, displays, and Hands-On-Throttle-And-Stick (HOTAS) functions. The IMTS has a very accurate engine simulation model, which makes it very useful for learning engine startup and emergency procedures.

Apprentice Technician Familiarization

The CF is presently experiencing a higher than normal attrition rate among experienced aircraft technicians. The resulting shortage of experienced technicians and influx of unskilled apprentice technicians has placed a high training burden on the operational fighter squadrons. The CF fleet school (10 Field Technical Training Squadron - 10 FTTS) has responded by providing additional training at the apprentice level. The IMTS is playing an unexpected, yet key role in the orientation of new technicians to the CF-18. The IMTS has proven to be extremely well suited to basic system familiarization and safety training.

Journeyman Technician Authorization and Technical Airworthiness Requirements

After Journeyman CF-18 technicians have received their type-specific training, they undergo a period of supervised On-the-Job-Experience (OJE) prior to being granted the responsibility of signing for aircraft servicing and repair tasks. A strictly enforced qualification system ensures compliance with Technical Airworthiness requirements. In order to reduce the time required to produce fully qualified technicians, the CF fleet school has begun to pre-qualify technicians at the school on many tasks, further reducing the training burden experienced by operational fighter squadrons. The IMTS will play a key role in this process improvement.

Advanced Troubleshooting

The IMTS supports malfunctions that range in difficulty from fairly simple Weapon Replaceable Assembly (WRA) or “black box” changes, to very complex wiring, fuel, or hydraulic malfunctions that require extensive testing and troubleshooting. The CF intend to add additional malfunctions to support the Advanced Flight Control System Troubleshooting course.

CONCLUSIONS

IMTS is a highly flexible training device that goes far beyond the traditional role of a maintenance simulator. The combination of the virtual cockpit and multimedia interactive panels make the IMTS extremely well suited to modern instructional techniques using multimedia, electronic technical manuals, and the display of simulation to a group of students. The IMTS virtual cockpit makes it possible to display activities and indications from the hardware cockpit to a group of students via the interactive panels.

Although the cost effectiveness of IMTS becomes very apparent when compared to the use of operational aircraft for maintenance training, cost alone does not offer a fair comparison. The IMTS is a vastly superior training device, with capabilities that far exceed what is possible or safe using a real aircraft. The IMTS provides the CF with the most effective method of simulating faults for realistic training of testing and troubleshooting on the CF-18. The acquisition and support costs of five IMTS were substantially less than the cost of modernizing one CF-18 aircraft.

The initial capabilities of IMTS have been extremely well received by the Canadian Forces and the Royal Australian Air Force. In concert with this initial success, the IMTS represents an entirely new product family that will undergo many enhancements and improved functionality as the product matures.

ACKNOWLEDGEMENTS

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Figure 17. IMTS CF/RAAF/Boeing/Atlantis Product Team

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ANNEX A
SIMULATION DEVELOPMENT ISSUES

Non-Recurring Engineering Costs (NRE)

When developing a new simulator, a portion of the engineering effort is consumed developing the first iteration and the remainder is used to produce the number of simulators eventually required. The design, fabrication, and production effort to develop the first example is called non-recurring engineering (NRE) and typically represents the largest portion of the overall program (from 70 to 90 percent). Once the initial example has been developed and tested, further identical simulators can be reproduced for a fraction of the NRE.

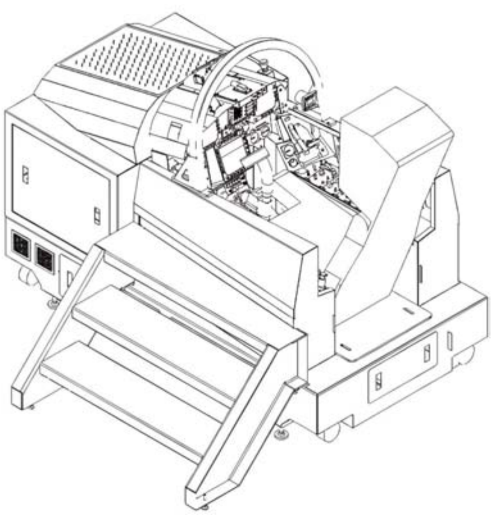

Figure 1. IMTS Cockpit Engineering Model

Figure 2. IMTS Cockpit Undergoing Integration

Hardware NRE

Of the total NRE, about 20 percent is typically used to design the hardware, including cockpit, display system, power system, and motion base if required. Most simulator companies will make extensive use of Commercial-Off-The-Shelf (COTS) components, to further reduce the hardware NRE.

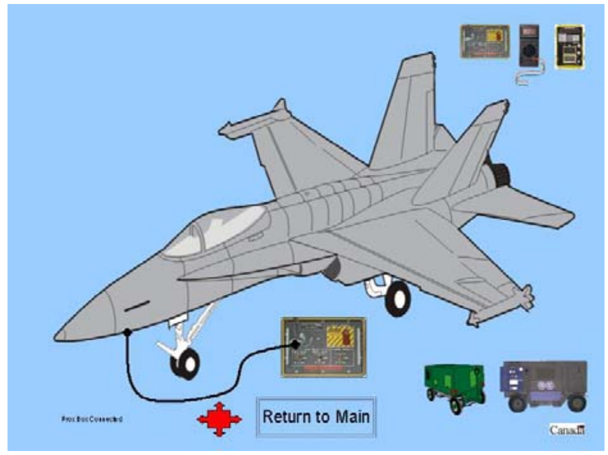

Figure 3. IMTS Early HMI Prototype

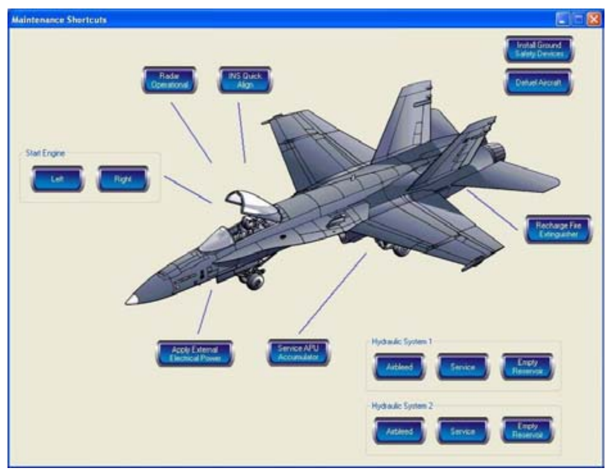

Figure 4. IMTS Maintenance Shortcut Window

Software NRE

The remaining 80 percent of the NRE is used for software engineering, including the engineering hours required to develop the following software components:

- Human-machine interface (HMI). This refers to the screen layout, malfunction controls, time acceleration, simulation parameters, and snapshot controls. The HMI component may not be aircraft-specific.

- Virtual aircraft simulation. This includes the video tree used for navigating around the 2D photo images of the aircraft, the 3D simulation, aircraft systems including mission computer emulation, flight control computer and associated systems, armament computer, radar, electronic warfare, communications and navigation systems, fuel system, hydraulic system, power generation system, environmental control system, and others.
- Virtual test equipment and ground support equipment simulation.
- Development and testing of maintenance procedures and malfunctions
- Drawings and technical documents, including maintenance and user manuals
- Acceptance test routines, test plans

CONCLUSION – ANNEX A

For typical simulation programs, at least sixty percent of the overall engineering effort is consumed developing software. For many military aircraft programs, this carefully constructed and costly software is never re-used for any other purpose, except subsequent simulator upgrades. The initial NRE is not wasted, since it was required to construct the simulator, but it would be beneficial to both the simulation company and the customer if ways could be found to derive additional value from this investment.

ANNEX B
THE FUTURE OF SIMULATION IN AIRCRAFT MAINTENANCE TRAINING – WHERE DO WE GO FROM HERE?

One way to derive additional benefit from the NRE is to create new products that can make use of a relatively unchanged core simulation model. One possibility is the desktop, or single-cpu version.

DESKTOP SIMULATOR

The desktop simulator would have the following characteristics:

- Able to run on a standard PC or laptop computer, properly equipped with a large hard drive, capable graphics card, and additional memory;
- Can be connected to a variety of standard PC displays, from large format displays, such as plasma or LCD monitors, to standard computer monitors or touch-screens having sufficiently high resolution;
- Able to run on a standard PC operating system
- Uses a standard PC pointing device to control the simulation (mouse, trackball)
- Does not have a cockpit, projection system, or other components associated with the full simulator
- Web or intranet accessible – anywhere, anytime
- Embedded assessment modules (formative, concurrent and summative)

Figure 1. Desktop Simulator – Medium Format

Possible Applications for Desktop Version

A desktop simulation could have many possible uses:

- With a large-format display system, it could be used to supplement existing simulators to handle peak training demands, or where budget limitations restrict the number of regular simulators available;
- With a portable medium format display system (30 to 42 inches diagonal), could be used to conduct training during deployed operations or at remote sites;
- With a conventional or flat-panel PC monitor (19 to 20 inches diagonal), could be used with individual students or small groups to increase the amount of time that each student can interact with a simulator
- Permitting many customer representatives to test simultaneously could accelerate simulator acceptance testing. Simulation quality may be increased by exposing the simulation to more testers;
- Used by simulator engineering, programmers, and management as engineering Software Development Facility (SDF);
- Aircraft engineering support could use desktop simulation to gain knowledge and experience with aircraft systems and for testing maintenance procedures; and
- Snags and Servicing Desk. Aircraft maintenance technicians could perform troubleshooting and component changes on the simulator while attempting to resolve stubborn or complex aircraft malfunctions. Scenarios could be tested on the simulator to ensure that faulty components are correctly identified before taking an aircraft apart to change a difficult or inaccessible component. Unnecessary component changes could be reduced, with corresponding cost reductions at the second –line and depot level.

Desktop Version Development Challenges

- Aircraft simulations are complex and are designed to run on a network of computers. It may require significant effort to get all of these programs to run on a single, non-networked computer, even if it has a very fast CPU and ample memory;
- Installation routines and procedures will need to be modified to provide a single computer install;

- Some simulations depend on hardware components that may not be easily emulated
- Simulations designed for a large display may require a high screen resolution which may not display correctly or even legibly on a smaller monitor; and
- There may be security issues associated with having a full aircraft simulation contained on a portable device such as a laptop computer

Processing Power – Desktop Version

When simulators are designed, they typically use several, state-of-the-art computer systems available at the time of the hardware Critical Design phase. By the time the simulator is completed and fielded, the design hardware has usually been greatly surpassed by new processors, memory, and other components. The newly available processing power can make it possible for a simulation that previously required several computers to be hosted on only one relatively standard PC.

Other possible simulation derivatives:

- Partial simulations used within training courseware. By re-using small sections of simulation code and graphics, individual systems or partial systems could be simulated, for example the hot fuel re-circulation system or a radio, such as the ARC-210, which is used in many aircraft types. A partial simulation could be made more portable, even web-based. Additional work may be needed, since modern aircraft systems interact extensively and may not react predictably if a background system such as the mission computer is missing or incomplete.
- Graphics, photographs, sounds, and 3D models could be re-used in other simulations, in a virtual environment;

  training programmes, or technical publication illustrations
- Avionic displays or sequences of maintenance actions performed on the desktop simulator could be recorded and used within technical publications or training courseware to illustrate troubleshooting and maintenance actions.
- Groups of local or geographically dispersed computers could be networked to share a single simulation instance and conduct team-based training. Standard PC-based audio communication hardware could be used to simulate intercom and radio communications.
- Aircrew. A flight model could be added to the IMTS for use as an aircrew trainer.

CONCLUSION – ANNEX B

The development of an advanced maintenance simulator such as the IMTS requires a large investment of time and money. The majority of this investment is used in non-recurring software engineering tasks.

By developing derivative products from the core simulation model, simulation customers can leverage their investment to provide additional training capabilities and value.

Simulation companies can generate additional revenues by helping their customers gain greater value through the re-use of NRE in new and innovative ways.

The IMTS is a new product with great potential for further derivatives and future capability growth and evolution.