EMBEDDED TRAINING FOR TACTICAL AIRCRAFT: ITS TIME HAS COME

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ABSTRACT

Embedded Training (ET) systems for tactical aircraft have shown promise over the years as effective training media. However, these systems have gained only limited acceptance because of concerns about impacts on aircraft availability, performance, safety, and affordability. Recent technological advances, however, show that ET can overcome these concerns and become a key component of the total training system for the next generation of tactical aircraft, such as those resulting from the Joint Strike Fighter (JSF) program.

In the next century, tactical aircraft must address a new training requirement. Not only will the pilot be trained to operate his aircraft and all its weapon systems, he will have to learn to operate in a more fully integrated joint battlespace. This will require familiarity with a myriad of support systems, joint forces and integrated command and control. The total training system of the future must also provide for delivery of training and mission rehearsal wherever the aircraft and pilot are deployed. ET is a viable training media to meet all these needs. In-flight, it can enhance the training fidelity of existing range facilities to support more complex training scenarios. It can also provide a "portable range" for team training capability anywhere/anytime. On the ground, ET can support continuation training wherever the pilot and aircraft are deployed. ET can link the aircraft with the emerging global training network system. New aircraft avionics systems can support these features with minimal impact on aircraft performance and availability.

Biographies

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A) Introduction

Tactical aircraft training requirements go well beyond simply training the pilot to operate the aircraft and its weapon systems. The strike warfare environment is becoming much more complicated and strike aircrew training developers must consider coordination with a variety of other assets, including AWACS, JSTARS, UAVs and advanced command and control systems as well as joint service operations. Aircrew training in this new environment, especially for tactical aircraft, continues to be a challenge. This paper reports in part on work done for the Joint Advanced Strike Technology (JAST) program Supportability and Training (S&T) Integrated Product Team (IPT) as part of the ET for Mission Rehearsal study. It explores how ET, as part of an integrated total training system, provides an affordable, effective solution for future tactical aircraft training needs. The legacy from past ET programs is reviewed and a roadmap for the phased implementation of ET on JSF is presented.

B) Embedded Training Overview

A variety of methods are in use for aircrew training, including classroom study, computer-based training (CBT), simulator training, and in-flight instruction. Classroom study and CBT provide overall information and review but lack hands-on realism. Simulators are improving, but have not been effective for training many air-to-ground tasks and continue to have aircraft concurrency problems. Training at range areas such as Red Flag and Fallon has consistently increased pilot proficiency, but in-flight range training is expensive and hampered by environmental and political restrictions. Some dangerous tasks cannot be trained on ranges, such as emergency procedures and high-speed/close-environment sorties. For mission rehearsal activities, terrain options for attack scenarios are limited by local topology and the ability of instrumented ranges to present the true tactical situation. Despite these limitations, range training is still the preferred method for training tactical air and air-to-ground tactics. However, range training opportunities are limited and pilot/crew skills degrade quickly between exercises. Deployed forces have often had no training other than for the aircraft. Areas outside of CONUS severely restrict low-level flight and much of the world has no suitable training ranges. At the JAST Industry Training Day in February, 1994, General Muellner highlighted the problems he faced as a USAF wing commander in Europe as a result of limited concurrent training opportunities for his pilots. US Navy pilots have experienced some degradation in proficiency during long carrier fleet deployments and the Navy is seeking suitable carrier-based training solutions.

ET offers an innovative training tool to address these problems. It can extend training beyond the aircraft simulator and the range, add realism to one vs. one, one vs. many, and many vs. many encounters, and provide a rich simulated tactical environment for both in-flight and ground-based (flightline, carrier deck, etc.) training operations. ET provides realistic training scenarios that permit increased utilization and exercise of aircraft equipment and capabilities without the risk, cost and complexity of duplicating these conditions in real-life situations. Past tactical air ET programs have shown that the realism of the range threat environment can be built into the aircraft, enhancing the ability of range training to present a realistic scenario to the pilot. A number of successful demonstrations illustrated ET's capability to inject virtual targets which appear real to the pilot, conduct engagements, and record results. ET can enhance range operation by interaction with range assets to provide a rich threat environment. It also allows more events per sortie by reducing dependence on ground-based threat generators at specific locations. ET also provides a means to reinforce, at the home base, proficiency gained during the range experience. Current programs such as the Joint Tactical Combat Training System (JTCTS) and DMSO DIS demonstration projects are building a network infrastructure to support wide area training activities. ET will allow aircraft to take best advantage of this new capability.

While overall pilot comments on ET performance have been positive, actual implementation has been limited because of overriding concerns with safety and cost. These include:

a) The impact of ET on avionics complexity
b) The impact of ET on avionics reliability, maintainability, and availability
c) Prevention of false alarms
d) Potential fixation by the pilot on synthetic targets
e) Implementation of safety features

Program managers were also concerned that the added burden of ET will add weight, use precious computing resources and the increase cost of the avionics system.

While these concerns are still present, a number of new aircraft are building the potential for ET into the aircraft as part of the avionics design. Advances in avionics technology with emphasis on common computation design and more use of software to achieve function allow easier implementation. Finally, emerging technologies from programs such as JTCTS and the F-22 will allow aircraft to be linked with the range and other aircraft to participate in networked exercises. These systems can support interplay between cockpit crews in the simulator and armed forces on the ground and in the air. On the F-22 program, the user community requested an ET capability to improve the effectiveness of range training and enhance in-flight training outside a range environment. JSF aircraft avionics will also support some level of ET, allowing mission rehearsal with combined forces. ET can support other planes, ships and ground forces using forward air controllers (real or virtual) and training simulators through DIS. Elements of the air war/attack scenario can then become part of the training scenario. This allows pilot skill gaps to be trained using ET by designing scenarios to address the problems.

In summary, ET can provide:

- A training package that is always concurrent with the aircraft, enabling maintenance of pilot effectiveness at any location.
- Improved training flight effectiveness. Training flight realism is enhanced by adding threats (virtual and surrogate), a realistic electronic warfare (EW) environment, and communications.
- An onboard performance measurement capability enabling immediate feedback to the student and an enhanced debrief capability.
- Just-in-time mission rehearsal on the flight line supported by the latest intelligence information.
- Networking as part of the integrated global training system proposed by the Training System IPT, WPAFB. This network would allow team training and participation in large-scale mission rehearsal exercises.

The ET system should be considered part of the total training system design. It is not a total solution, simply another medium for delivery of training. The Instructional System Development (ISD) process would define what training tasks are accomplished by ET, with users central to ET requirements development. Finally, the ET system would be designed to maintain the integrity of all aircraft systems and ensure the safety of the aircraft, the pilot, and all supporting personnel. The ET mission is to train the pilot to operate the weapon system at its maximum performance level and maintain his proficiency at that level wherever and whenever the aircraft is deployed.

C) Embedded Training Requirements

Historically, aircraft platforms have been designed for mission implementation/execution with little regard for their use in training. Use of the aircraft platform in the total training system can be greatly enhanced with the implementation of ET. Figure 1 depicts the additional capabilities needed to support in-flight and ground-based ET. For in-flight ET, an interface must be developed to support networking, virtual target insertion and cueing, scoring and performance measurement. Sensor displays must be supported by injecting sensor video images into the aircraft display system. For ground-based operation, a simulation universe must be built in which aircraft training scenarios can operate. The ET environment must provide all necessary cueing normally provided by the real world. All aircraft indicators should respond as "in-flight" using a mission computer-hosted ownship model. Finally, network interface provisions must be available to allow aircraft interactions with other players and/or an evaluation/control site participating in the scenario. Other external requirements include the development of scenarios and a database to support the system, especially important in mission rehearsal operations where the accuracy of the database and currency of intelligence information is important. Data recording for performance measurement and mission debrief/planning evaluation may also be required.

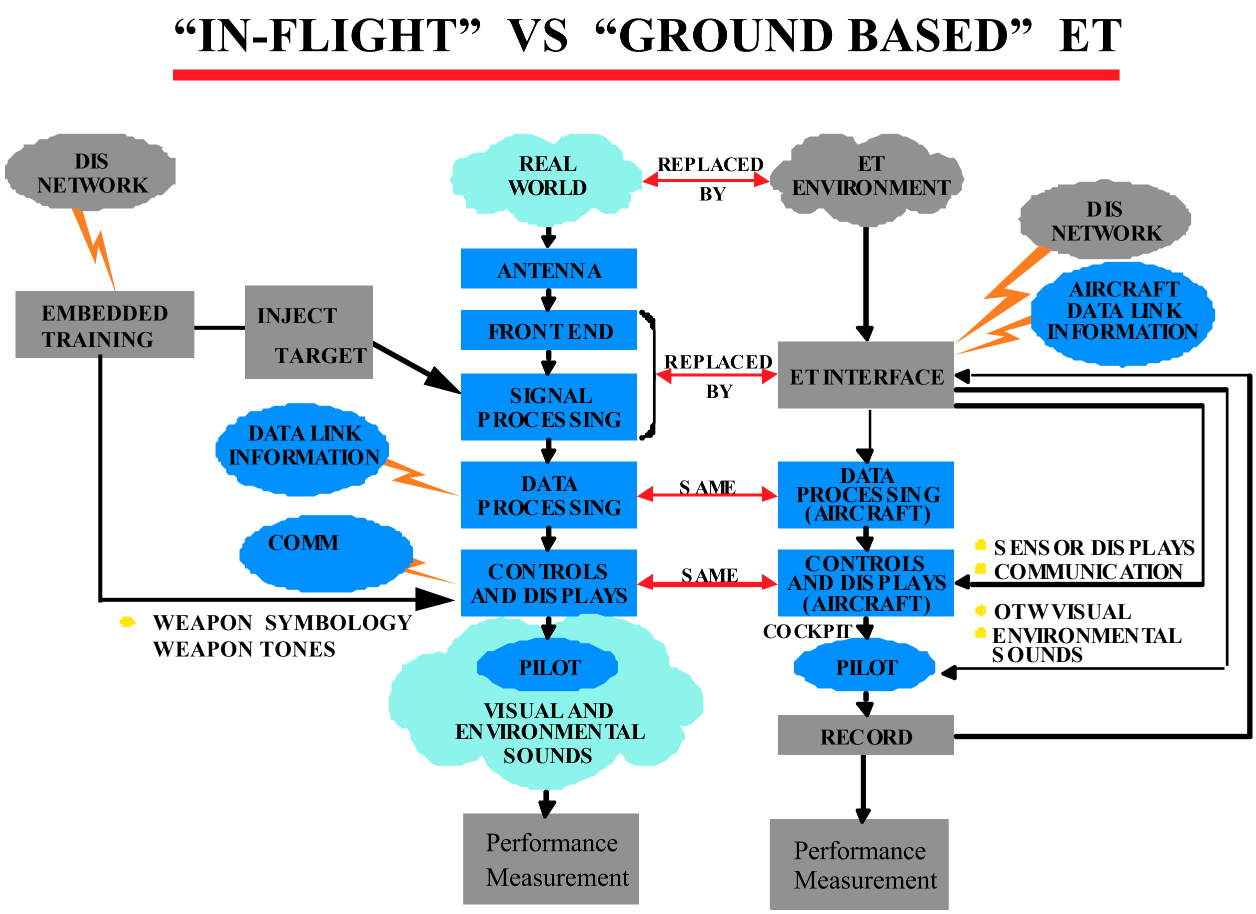

Figure 1. Capabilities Required for Embedded Training

D) Lessons Learned from Past Programs
Past ET programs for tactical aircraft have demonstrated many of the technologies needed for JSF ET, providing a significant risk reduction. A summary of these programs and technical risk reduction follows:

F-16 OBEWS. The F-16 Onboard Electronic Warfare System was developed in the 1980s to provide expanded onboard training capability for the F-16 EW system. OBEWS consists of an external pod interfaced through a MIL-STD-1553 bus, operating in conjunction with onboard systems, including the ALR-69 warning receiver, ALQ-119 jammer, ALQ-131 jammer, and ALE-40 dispenser. Special software was developed for the F-16 radar warning receiver (RWR) and central computer (CC) to recognize the OBEWS pod and drive aircraft systems based on OBEWS inputs. Operationally, the OBEWS pod provided a virtual electronic environment. The system includes the ability to pre-position "virtual" emitters along the expected aircraft flight path. The OBEWS terrain model determines visibility and presents active simulated returns to the RWR and ECM equipment over the 1553 bus in real time. In operation, a scenario containing threat locations and characteristics is loaded to the OBEWS modules developed using the AF Mission Support System (AFMSS). Aircraft position is determined using an onboard ground position system (GPS) receiver and/or inertial navigation system (INS). The emitter model simulates multi-mode emitter operation based on ownship position, emitter location and a library of expected emitter tactical responses to ownship actions. The F-16 avionics inserts these "virtual" emitter targets with the actual emitter targets on applicable cockpit displays and warning devices. Pilot actions are recorded for debrief. While the F-16 OBEWS technology was successfully demonstrated, the system was not implemented because of affordability concerns. This program demonstrated that an embedded system using a synthetic threat system could be used to present realistic virtual threats on all applicable cockpit displays for training. The pilot accepts these threats as real and operates against them. The program also showed that the costs of embedding this capability into an existing avionics system could be prohibitive.

F-22 ET. The F-22 avionics system provides an ET capability for use in-flight, designed to support training of A/A combat and provide simulated ground threats to integrate ground threat avoidance with A/A combat training.

There is no A/G target/attack capability. The system is designed for use with other F-22s using the F-22 IFDL to transfer information between ET modules. Other aircraft can participate in a support capacity, but with minimal training value because they are not part of the network and do not have the F-22 ET function. The F-22 ET module provides a training environment which merges the real world with simulated threats. It provides an ACMI interface to allow participation on instrumented ranges and sensor simulations that modify or generate sensor information to allow participating aircraft to change identity. The ET module performs simulated missile flyouts and scoring which include the effects of countermeasures (CMs) such as jamming and expendables, target signature, seeker dynamics, and pilot maneuver in determining miss distance and the probability of kill (Pk) of the missile. Data is recorded for later presentation as part of the debrief process. The F-22 program has demonstrated that an embedded capability can be provided at an affordable cost when designed as part of the avionics development. It has also shown that this can be done with minimal impact on the avionics design process and few design compromises. While training effectiveness is still not proven, F-22 ET promises a significant training effectiveness multiplier at tactical ranges and the capability for in-flight training outside a range environment.

HYDY. The HYDY is a program of the Fighter Aircraft Facilities Engineering branch at Point Mugu, CA. Program objectives were to demonstrate the extensibility of DIS to support high dynamic vehicles, address issues such as bandwidth, protocol and data latency, and demonstrate a virtual target on a "real" radar with sufficient fidelity that it would be a valid target to the pilot. The Point Mugu facility has a lab in which an F-14 cockpit containing a full avionics suite can be "flown" on the ground. Its radar is pointed out to sea and targets can be flown against it. For this study, a special hardware box was designed which allowed a virtual target to be injected into the radar. This virtual target was generated by a simulator and presented through a DIS network. A test was run with a combined "live" target flying at sea and a virtual target on the radarscope, and shown to trained operators. They were not able to distinguish the difference. Although this project has not yet been carried through to the flight test phase due to lack of funding, it did show that virtual targets through a DIS network can be presented realistically to a fighter pilot in real time. This program demonstrated that a network interface can support virtual target insertion on live sensors.

Agile Warrior and the Rockwell Cockpit Virtual Concept Study. The Agile Warrior Virtual Concept study investigated using helmet-mounted displays (HMDs) to provide a cockpit ET capability. In one demonstration, a simulator using a DIS interface flew as a wingman with the X-31 on a cross-country attack mission. Information typically provided on the HUD was displayed on the HMD. It was determined that a simulator connected through a DIS interface could be linked with a flying aircraft; thus a combined "live" and simulated mission could be flown. This demonstration showed that virtual and live forces can be integrated in a common mission with training values for both parties. It also showed that the networking problems and latency issues can be addressed. Finally, it demonstrated that HMDs can be used for training and that pilots will accept and use them.

US Army Studies. The US Army has conducted several studies analyzing the use of virtual environments and distributed simulation to maintain proficiency for ground forces. One study conducted in the mid-80s demonstrated the effectiveness of these tools in addressing this training problem. In the field, army tankers gained a significant improvement in their war-fighting skills. In garrison, there was a noticeable degradation. However, with the availability of a distributed simulation system in garrison, these troops were able to maintain and even improve their skills. In one example, NATO armies competed in an annual exercise in Grafenwehr, Germany, called the Combined Arms Tactical Training Exercise (CATT SHOOT). Until 1987, the US Army had never won the competition, due in part to training limitations in the field. In addition, most of the range training was done with static targets. In the summer of 1987, the Army trained three platoons for the CATT SHOOT. In addition to range training, the crews were given unlimited opportunities to practice maneuvering vehicles and shoot "pop-up" enemy targets in a simulated environment. They placed first and third in the competition. The conclusion drawn was that physical training in a realistic virtual environment not only trains the use of weapon systems but also improves "putting ordinance on target." A 1987 policy statement by the Army vice chief of staff requires new Army systems to justify why ET is not incorporated. The Army now uses simulated munitions and weapons almost exclusively for training with a payoff of lower costs and better trained soldiers. While there is not a direct correlation to tactical aircrew training, the ability of a simulated environment to support transfer of training has been shown.

E) Lessons Learned for ET

Past ET programs have shown that the realism of the range threat environment can be built into the aircraft, enhancing the ability of range training to present a realistic scenario to the pilot. Ground-based training can improve performance in-flight and reduce the number of flights needed to achieve proficiency. ET programs have shown that effective training can be provided in the cockpit. ET can provide realistic scenarios embedded in the avionics to support presentation of a high-fidelity virtual environment and bring this capability to the cockpit for use in-flight and on the ground. ET will also support other planes, support ships and ground forces using JTCTS, forward air controllers (real or virtual), and training simulators through DIS. Each element of the air war/attack scenario can become part of the ET scenario, allowing pilot skill gaps to be trained by designing scenarios to address the problems.

Affordability payoffs from ET include:

- A reduction in peacetime A/C accidents. This has already been seen at Red Flag with the increased use of simulators.
- Weapons system proficiency improvements which reduce the sorties required per kill. This result follows from the Army CATT SHOOT experience and basic learning theory, i.e., more practice leads to better performance.
- Enhanced training mission effectiveness through the use of networking, virtual targets, and situations allows more effective use of range flight hours, improving pilot throughput rates and reducing training costs.

F) ET Development Roadmap

ET capability can be built in logical steps, with each level providing additional capability at an additional cost in development and processing. The ET roadmap shown in figure 2 defines four distinct levels of ET and the types of training tasks supported at each level, identifying the potential for technology capture to support ET development and proposing potential areas of technology maturation to help realize ET capability in aircraft such as the JSF. In-flight, the ET function will be additive with minimal impact on existing aircraft systems other than those required for hooks to obtain status of the aircraft. This capability would enhance range operations and allows training of air-ground weapons without ranges. Ground-based ET is more extensive and may require an alternate OFP to free up processing, but allows simulation of aircraft systems and resolves concerns of safety of flight and weapon systems integrity. It would provide a deployable training capability with the aircraft which is always concurrent and usable whenever and wherever required by both aircrew and ground crew.

In-Flight A/A Embedded Training (Level 1)

Level 1 ET embeds an in-flight training capability in the aircraft for A/A engagement and ground-to-air threat avoidance mission tasks. The ET module would interface with existing onboard avionics to insert virtual targets into cockpit displays and provide virtual weapons to engage the targets. A networking capability would allow team training and the training of aggressor tactics. For close-in A/A engagements, the module would monitor the engagement with other network participants, provide virtual weapons, and score the action. For beyond visual range (BVR) engagements, ground threats and virtual targets would be generated onboard or provided through a network link. The virtual targets would have sufficient fidelity to support mission rehearsal exercises, primarily by modifying/ inserting reports sent by the sensors to mission software. The sensors are not impacted. This approach is valid for sensors that provide discrete target information that is processed by mission software. Virtual models for A/A weapons normally employed on the aircraft will be provided for training weapons employment and A/A engagement. The virtual targets could be fixed, moving, or driven from a networked source. This capability could also support team training missions.

Basic System Implementation - Level 1 ET software will run in the mission computer. The ET module modifies and create new sensor reports similar to F-22. Sensor reports are broadcast over the avionics buses, so that the ET software can receive them (a different technique would be required if the messages were sent point-to-point). ET can then examine the reports and modify them if necessary. This scheme allows ET to accomplish its task with minimal impact to the other mission software, and no impact to the sensors. Safety issues are addressed by allowing the Stores Management System (SMS) controller software to be responsible for determining if ET mode can be entered. SMS then informs the rest of the system when entering ET mode, as was done in F-22. This reduces the possibility of inadvertent weapon release.

Training Tasks Supported - Level 1 ET supports a wide range of training tasks, including:

- Sensor Management
- Situation Awareness
- Target Sorting
- Offensive Tactics
- Ground Threat Avoidance
- Low Observability Tactics
- Display Management
- Launch Envelopes/Steering Cues
- Post-Launch Maneuvers

Risk - Level 1 ET has a low technical risk; the technologies necessary for its implementation are already in place. In-flight the ET function is only required to provide a small delta to the real world. Most external inputs are "free" with no modifications required. Data collected by the sensors (including the "human" sensor), such as out-the-window (OTW) visual, terrain, weather, G-forces, etc., is also available for ET, with only minimal changes required, i.e., the "sensed" data requires the insertion of the target (or modification of surrogate target). The main function of the ET module is to provide target insertion into the sensor data. This is relatively easy for targets that appear as icons on a computer-generated graphic, as is the case for airborne targets The risk is further reduced by the extensive F-22 ET development.

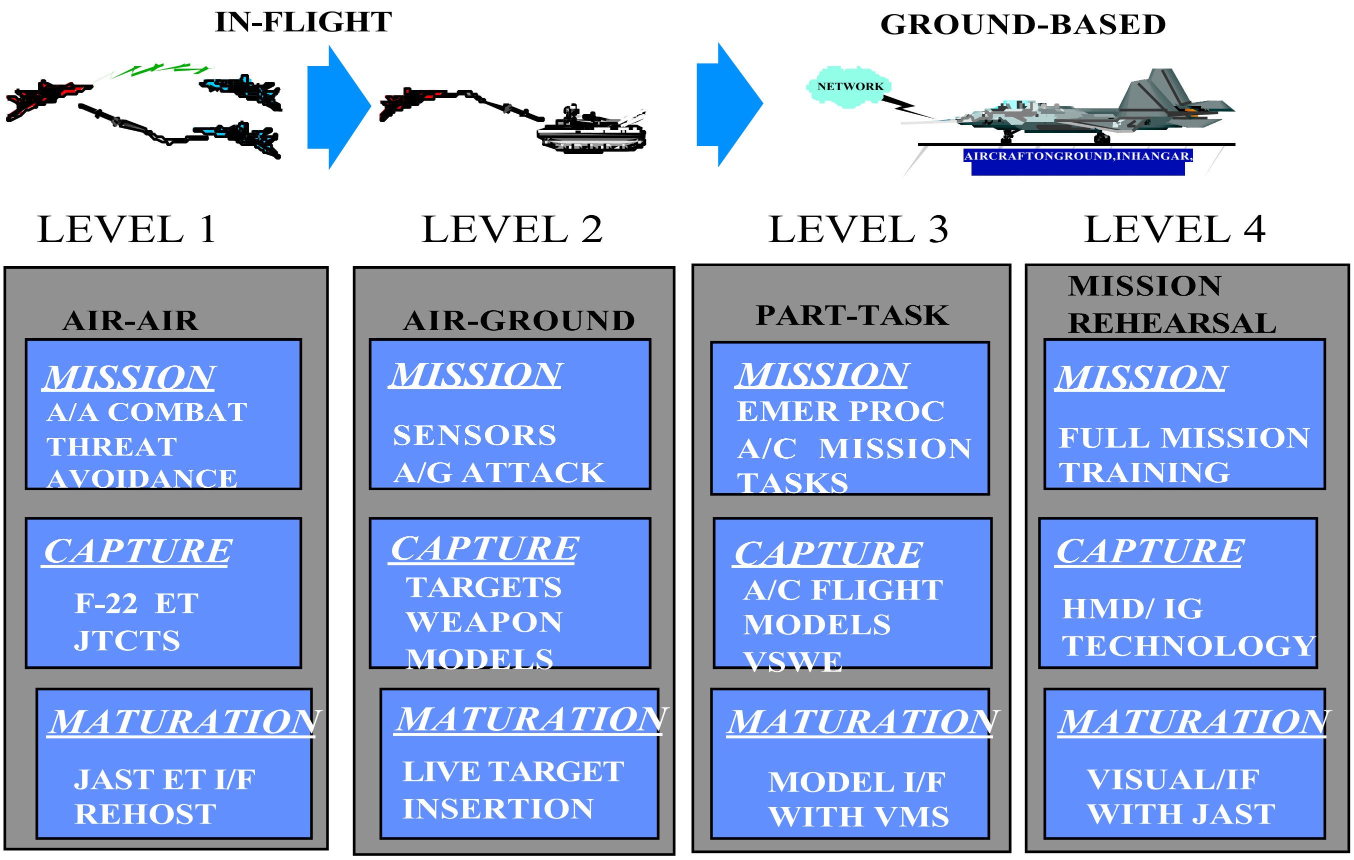

Figure 2. JSF Embedded Training Development Roadmap

In-Flight A/G Embedded Training (Level 2)

The in-flight air-ground ET mode (Level 2) incorporates the capability of Level 1 and adds a training mode for use of onboard sensors and smart weapons to locate and designate a target on a SAR display, acquire a target on an EO or IR display, lock-on and fire a virtual weapon and score results as part of training missions anytime, anywhere. The ET system would interface with existing onboard avionics to insert virtual targets into sensor displays and provide virtual weapons to engage the targets. All aircraft systems and sensors function normally, including all terrain information provided by the video sensors. Virtual targets and cues are added seamlessly to existing sensor scenes and associated aircraft displays, including any weapon tones and HUD or HMD symbology. However, since all targets are virtual, no visual target is seen OTW. All existing aircraft displays are maintained and all ET actions are additive. No existing targets or features are masked. The virtual targets would have sufficient fidelity to support training for use in target identification and attack for mission rehearsal exercises. Virtual models for smart weapons normally employed on the selected aircraft would be provided for training weapons employment and A/G attack missions. The virtual targets could be fixed, moving, or driven from a networked source. Through a network, this capability could support team training missions and special operations such as "buddy lasing" tactics. This capability would be applicable to any strike aircraft that employs digital sensor displays and smart weapons.

Basic System Implementation - The Level 2 ET system can be implemented as part of the existing sensor processing system. ET tasks required include the capturing of sensor imagery from sensor processors and interfacing with onboard avionics to obtain aircraft inertial data and digital sensor images to seamlessly insert virtual images into the scene in real time. A second activity is required to properly model weapon cues, including tones and symbology. The approach adapts existing weapon simulation models to operate on virtual targets and allow acquire, lock-on, and launch modes to be simulated.

Training Tasks Supported - Level 2 ET supports a wide range of training tasks, including:

- Mission Rehearsal
- Weapon Delivery
- Situation Awareness
- Ground Threat Avoidance

- Multi-Sensor Techniques
- Stores Management
- Target Acquisition
- Launch Envelopes/Steering Cues
- Target Designation
- Use of Sensor for BDA
- Non-cooperative Target Recognition
- Buddy Lasing and Other Team Tactics

Risk - In-flight operation requires that ET code run real-time in an avionics processor, which involves medium risk. Targets can be inserted into the video after the sensor processing is complete, minimizing the impact to the avionics, because the sensor software is not affected. Another design approach being considered is to incorporate the sensor insertion module inside the sensor (rather than a post process). This impacts the sensor, but eliminates issues associated with interfacing with the sensor video. There are many technological challenges to handling optical sensor image target insertion beyond the demonstrated capabilities exhibited by the radar target injection methods. First, the update rate must be sustained. Second, perspectivization of the image, both in attitude and size, would have to be rendered, since the pilot would be sensitive to unnatural projection. Finally, the target portrayal should not be perceived as unnatural either in brightness, shading, or activity to enable appropriate targeting practice by the pilot.

Ground-Based ET for Part-Task Training (Level 3)

Ground-based ET for part-task training (Level 3) provides a part-task training capability in the cockpit for both flight and sensor training. Level 3 tasks include an ET interface which must provide the entire environment for training. ET capabilities will be optimized to support part-task training, including emergency procedures, sensor training and mission preview. On the ground, ET can provide a more controlled training environment where a much richer threat environment can be provided with minimal risk to the pilot and the aircraft. This allows training scenarios that are not possible while airborne. Ground-based ET provides training that is co-located with the pilot, wherever he is stationed. It supplies a training capability that is always concurrent with the aircraft OFP and inherently has the same cockpit configuration as the aircraft being flown.

Clearly, if the use of the aircraft as a simulator were simple and straightforward, it would already be in widespread use. The challenges include both the technical issues of how to bring simulation into the aircraft system and aircraft operational issues of ground operation without engines, including selective powering of aircraft systems, powering and cooling aircraft systems without damage or loss of service life, and maintaining pilot comfort to provide an environment suitable for transfer of training.

Basic System Implementation - Ground-based ET requires significant processing resources, which, since the mission computer no longer has to fly the plane, should be available. The mission computer for new aircraft such as F-22 and JSF are projected to be general-purpose multi-processors with dynamic task allocation, capable of executing a typical simulator load. The data processing and display processing elements of the FP would be maintained but data sources from sensors and aircraft systems would be simulated, requiring major revisions to the OFP to ensure safety and system integrity is maintained. A simpler solution might be to develop an alternate OFP for training. This load would have a high degree of commonality with the flight OFP but would substitute simulated components where applicable. It would be developed strictly for training and would redistribute the JSF computational assets to perform the training mission. All assets formerly allocated to sensor processing would be freed up and reallocated to sensor simulations and tactical environment simulations. The ground-based ET mode will support a mode where the threat environment could come from either onboard simulations or from the network. Initial discussion with JSF maintenance subject matter experts (SMEs) suggests that an alternate OFP could be acceptable. This approach would minimize safety concerns since the training OFP load would not be loaded in-flight and would guarantee that critical aircraft systems and weapons would not be active. Techniques for quickly loading either OFP version, perhaps using a specialized data cartridge, may need to be considered.

Training Tasks Supported - Level 3 ET supports a wide range of training tasks, including:

- Emergency Procedures
- Network for Team Training
- Part-Task Training for Sensors
- Special Operations such as Buddy Lasing
- Part-Task Weapons Delivery
- Cockpit Familiarization
- Mission Preview
- Continuation Training
- "What-If" Mission Scenarios
- Maintenance Mission Rehearsal
- Non-cooperative Target Recognition
- Maintenance System Help Files

Risk - During ground-based ET, the ET function is required to provide the complete environment. None of the external inputs required by the avionics are available. In addition to creating all the inputs that would normally be provided by the outside world, the ET function must convince the avionics that the aircraft is operating normally so that no unusual indications will appear to the pilot. This is not trivial, considering that the operating conditions are far from normal. The engines, generators, and flight controls are powered off, along with many other systems designed to report all problems to the pilot since their operation is critical. Preventing the avionics from reporting anomalies requires some impact to the avionics, and some of the modifications will be difficult to make because safety-critical systems are affected. The most difficult task may be to decouple the aircraft avionics from its sensors to allow this alternate virtual world to be presented in such a way that aircraft system integrity is not compromised.

Ground-based ET is also constrained by power and cooling of aircraft avionics and the pilot with the engines off. Methods for powering the aircraft on the ground with engines off without reduction in service life must be developed. In addition, with the engines off, cockpit air conditioning is not present, and pilot comfort cannot be maintained. While these are not problems with ET per se they must be solved for ET to be viable. Cooling and power must be provided for avionics processors and the pilot. Power and cooling issues are also a requirement for supportability because maintainers also need to power the avionics on the ground. For example, a Marine maintenance SME commented that in the field, a local highway could be the repair depot and the aircraft would be very difficult to maintain without the ability to power systems on the ground with a minimum complement of special hardware. On the JSF program, ground power and cooling is being addressed as a Concept Development phase requirement.

Ground-Based ET for Mission Rehearsal (Level 4)

Level 4 ET provides a ground-based mission rehearsal capability that would support full fidelity missions and include a personal display device supporting a full-field-of-view visual. This capability would provide a "WST in the cockpit." Level 4 tasks include an ET interface which must provide the entire environment for training, including mission rehearsal and debrief. Mission rehearsal is distinguished from part-task ET applications in that it includes a full OTW capability. This may include interfaces with support equipment outside the aircraft to access real-world intelligence imagery and associated database information. The focus of this training is the use of real-world intelligence imagery to enhance the pilot's ability to practice mission procedures on representative real-world target imagery. This system would support a high-fidelity mission rehearsal player, and includes a high-fidelity visualization system integrated with the cockpit.

Basic System Implementation - The Level 4 system adds visual and external system support to the Level 3 capability. Even with optimistic anticipated growth in on-board processing power, an external image processor will be required. The commercial marketplace is putting a lot of development into software image generation, low-cost display devices and video broadcast which may be adaptable to the aircraft environment, making this capability a reality at an affordable cost.

Training Tasks Supported - Level 4 ET supports a wide range of training tasks, including:

- Mission Rehearsal
- Low-Level Tactics
- Situation Awareness
- Team Training/Tactics
- Mission Preview
- Aggressor Tactics
- Mission Planning
- Tactics Demonstrations
- "What-If" Scenarios
- Mission Debrief

Risks - Level 4 ET is presently high risk, with the same risk issues as Level 3 plus new risk issues, including the maturity of image generators and display devices and the need for a high bandwidth interface to support appended ET support. While an external IG is required, the display device is the most critical item. Flight-quality HMDs will be used in new aircraft in lieu of HUDs, but they are unsatisfactory for training because of lack of fidelity. A number of non-helmet solutions are being developed for the commercial marketplace, including canopy projectors and retinal projection using a micro-lasers which may solve this problem. Another problem is simulator sickness. The current solution to that problem involves providing motion cues which are probably not possible in the aircraft.

G) Benefits and Savings from ET

In-flight ET impacts on aircraft avionics are small and offer significant benefits in training capabilities. New aircraft designs (i.e., F-22), at the users' request, have included airborne ET in their system designs. Ground-based ET provides capabilities that cannot be achieved with any other form of training. Using the aircraft as a solution to the deployed training and carrier-based problems can provide significant cost savings and improve readiness. ET for maintenance training also offers additional operational benefits. But ground-based ET is high risk and high cost due to add-on equipment required, new software development and operational problems of operating avionics on the ground and maintaining pilot comfort.

The full benefit of ET is difficult to evaluate. Studies accomplished to date on the concrete value of ET are limited to paper assessments and judgment calls. Related studies are historical in nature and come from other defense systems and different training media. Data specific to ET effectiveness and efficiency is sorely lacking. Despite these limitations, ET offers strong potential to provide both added effectiveness to aircraft training and significant cost savings. These include:

- ET has the potential of reducing the time required by pilots to achieve in-flight proficiency.

- ET training exercises can overcome skill degradation which typically occurs over time following an operational range exercise.
- ET, when fully integrated within the total training system, has the potential of improving overall training effectiveness and cost efficiency.
- Use of ET technology allows more effective use of limited flight hours for training.

An analysis for the JSF program using these factors projected life cycle cost (LCC) savings approaching $1 billion due to improved off-range training capability and projected reductions in flights needed to achieve proficiency.

References

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3. Embedded Training Technical Demonstration Plan, Naval Air Warfare Center/Training Systems Division, Contract: N61339-95-K-0012, CDRL A006.

4. Embedded Training for Mission Rehearsal Study, Final Report Naval Air Warfare Center/Training Systems Division, Contract N61339-95-K-0012, CDRL A001. (This document includes an extensive set of references on embedded training used as part of study.)