ON-BOARD TRAINING IN ELECTRONIC COMBAT

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ABSTRACT

This paper examines the advantages of adding On-Board Training functions to programmable Electronic Combat devices.

The flexibility now built into many EC devices makes it possible to modify and add to the basic functions of the devices and to communicate with other devices. On-Board Training functions can be added to such devices. For Electronic Combat equipment, On-Board Training (OBT) involves injecting simulated radar signals into EC devices to provide realistic threat displays and responses for training purposes. A hypothetical application is described. Alternative implementations on several levels of complexity are discussed. An OBT retrofit application is described, the On-Board Electronic Warfare Simulator (OBEWS), which is being designed for the U.S. Air Force. Aspects of OBT training effectiveness and system configuration are discussed. Problems with OBT systems are examined -- task definition, capacity limitations in host equipment, interaction with basic operational functions, and long-term maintenance. Special aspects of land-based and sea-based OBT are presented.

This paper examines the advantages in incorporating On-Board Training (OBT) functions as an integral part of Electronic Combat devices. OBT functions can greatly enhance the training value of operational EC equipment carried on aircraft or other vehicles by injecting a simulated radar emitter environment into the equipment during training missions. A wide variety of implementations can be developed to fill particular training requirements and to integrate with specific EC equipment. A hypothetical example and an actual retrofit implementation discussed in this paper encompass a range of alternatives. Each approach has its advantages and problems. However, any properly-designed OBT system will greatly enhance the training utility of the EC equipment in which it is embedded.

Electronic Combat Devices

Radar-oriented EC equipment is generally designed to acquire and identify hostile emissions and to manage countermeasures resources to defeat the hostile emitters. EC equipment comes in a number of variations. Some devices such as the AN/ALR-69 Radar Warning Receiver provide passive detection and identification of radar emitters. Manually-controlled jammers such as the AN/ALQ-119 generate jamming signals under manual or semi-automatic control. Newer integrated systems such as the AN/ALQ-99 Tactical Jamming System perform integrated identification and Electronic Countermeasures (ECM) functions automatically.

Figure 1 shows the basic operation of a typical EC device, a smart jammer operating under software control. The receiving hardware receives signals from the environment. The interleaved signals are separated out by the acquisition software and matched to an emitter data file for identification. The signal data is sent to the display hardware for operator viewing. The display hardware typically displays visual symbols identifying the threats received, as well as audio tones for special alerts. Signal data is also sent to the jamming management program, which selects jamming resources and controls the jamming hardware. The jammers under software control then transmit jamming signals. Jammer control displays are usually provided to permit the operator to monitor and control the management of the jammer hardware.

On-Board Training in Electronic Combat Equipment

For Electronic Combat equipment, On-Board Training consists of injecting simulated emitter signals into operational EC equipment during actual training missions. Injection of signals provides realistic threat displays and countermeasures management in the operational EC equipment for training purposes. The equipment operator sees simulated emitters appear on his operational equipment during actual operation, as if actual transmitters were in place in the environment. Countermeasures management functions can also be monitored by the operator. Since the EC device behaves as if it is seeing actual emitters, the operator can gain experience with how the countermeasures manager responds to actual threats. Yet the emitters do not actually exist in the physical environment -- they originate in the OBT software.

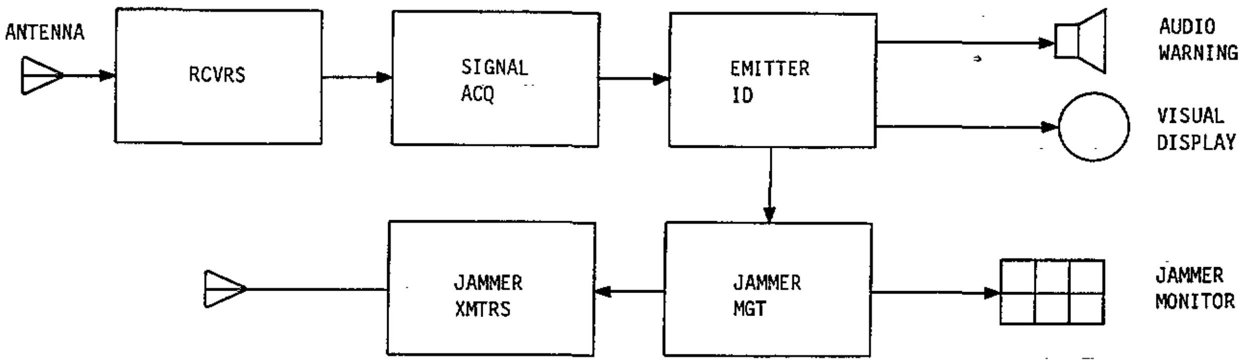

Figure 1. Hypothetical EC System

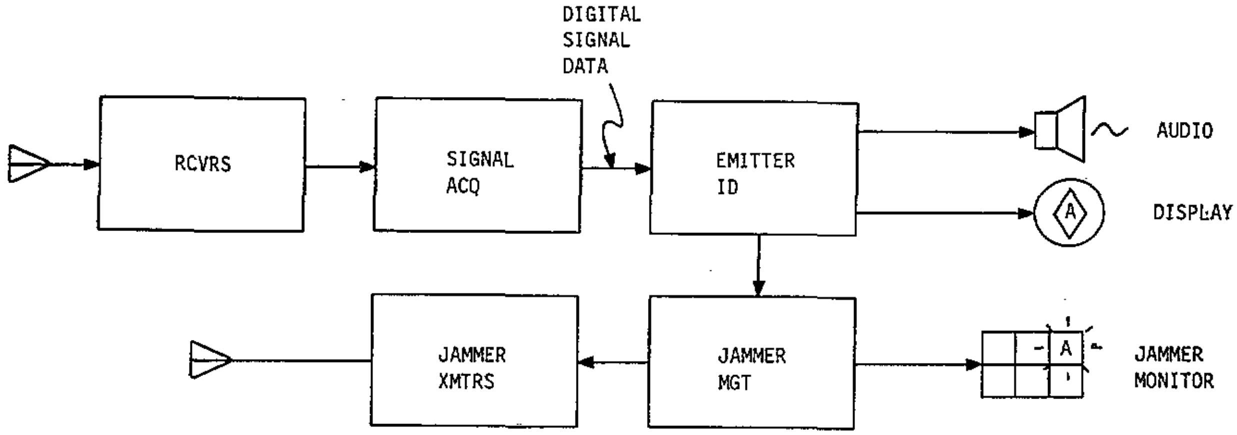

Figure 2. OBT Signal Processing

Figure 2 shows how this would work on the hypothetical smart jammer described above. The simulated emitters may be injected into the identification process just before or after the signal acquisition stage. The controlling software then treats the simulated signals the same as any other signals. The simulated signals are identified and displayed to the operator. Jammer resources are allocated to the simulated signals and the results displayed on the jammer monitor. For security reasons, it is likely that the jammer hardware would not actually radiate jamming signals against the simulated emitters.

Levels of Simulation

The emitter simulation can be done on several levels of complexity. At the simplest level, the emitter simulator may inject one or more signals at a constant bearing and simulated range. The emitters to be injected may be selected automatically or chosen by the operator. In either case, the operator would see a static emitter display and jammer allocation.

At a higher level of complexity, the emitter simulator could simulate emitters stationed at specific ground locations. As the ownship turns or moves along a path, the relative bearing of the simulated emitter would change accordingly. This simulation of emitter position can greatly enhance training realism during a long mission or in a maneuvering ownship. This level requires more data and processing capability to determine the current position of the ownship, the positions of the simulated emitters, and their bearing and range.

At the highest level of realism, the On-Board Training functions can include a dynamic emitter simulator to mimic tactical behavior of the simulated emitters. The emitter simulator can cause the simuated emitter to switch between operating modes according to tactical conditions. For example, a simulated radar-controlled weapon system can be led through a sequence of modes -- long-range search, short-range target track, and weapon launch. The simulator can even cause the simulated emitters to respond to the jamming signals that the EC equipment is generating against them. Thus, the successful jamming of an emitter can prevent further action by the simulated threat or can cause it to switch to an ECCM mode of operation. At this level of realism, the simulated threat emitters will be virtually indistinguishable from actual threat emitters. Even the real-time tactical behavior of the simulated threats will show up on the OBT EC equipment.

Signal Injection Points

The simulated signals may be injected into the EC equipment in several forms. Figure 3 illustrates the various kinds of possible signal injection. First, the signals may be fed to the receiving antennas as modulated RF signals. In this form, the signals go through the entire receiving and identification process as real signals. This approach requires RF generating equipment, which adds to the size, weight and complexity of the device. Furthermore, the generation of classified RF signals can pose security risks.

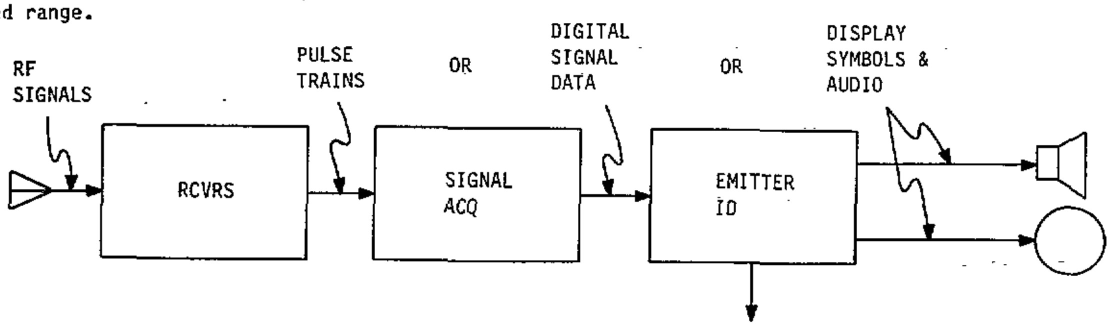

Figure 3. OBT Signal Injection Points

It may be desirable to bypass the antennas and receivers, and inject the signals as pulse trains directly into the signal acquisition stage. Even this method, however, can require considerable complexity in hardware to generate and update the pulse trains in real time, typically at a rapid rate. If direction finding is accomplished through signal strength or phase comparison, the digitized signals must be modified rapidly to simulate the changes in bearing.

As an alternative to generating pulse trains in real time, it is often possible to inject digital pulse descriptors into the software operation during the acquisition or identification phase. The feasibility of this approach depends on the design of the particular host EC device -- there may not be any practical method for injecting these "software signals" into a given software process. If this approach does prove feasible, however, it holds a number of advantages. Most importantly, it does not require a great deal of extraneous hardware for generating RF signals or analog pulse trains. The prime disadvantage of this approach is that it requires modification of -- or at least coordination with -- the operational software of the host EC device.

Finally, the simulated threats may be inserted into the host EC equipment at the display stage. The OBT functions could bypass all the signal processing operations and insert threat display symbols into a software display file or into the display hardware. This approach has the advantage of simplicity. However, this simple display function would probably fail to provide auxiliary effects such as audio warning tones in a receiver or jamming resource allocation in jammers. Such deficiencies could be tolerated or made up for with additional external hardware or separate internal audio functions.

Mission Data Recording

On-Board Training lends itself to mission recording for post-mission debriefing. Since emitter signals are being simulated artificially and injected into the EC equipment, it is a relatively simple matter to record the emitter parameters and the responses of the equipment. The recorded emitter and equipment data may be used later to reconstruct the simulated threat environment and the response of the equipment -- and its operator -- to the threats.

OBEWS -- An On-Board Training Retrofit

The On-Board Electronic Warfare Simulator (OBEWS) illustrated in Figure 4 is currently being developed by AAI Corporation for the U.S. Air Force. OBEWS is designed to provide true

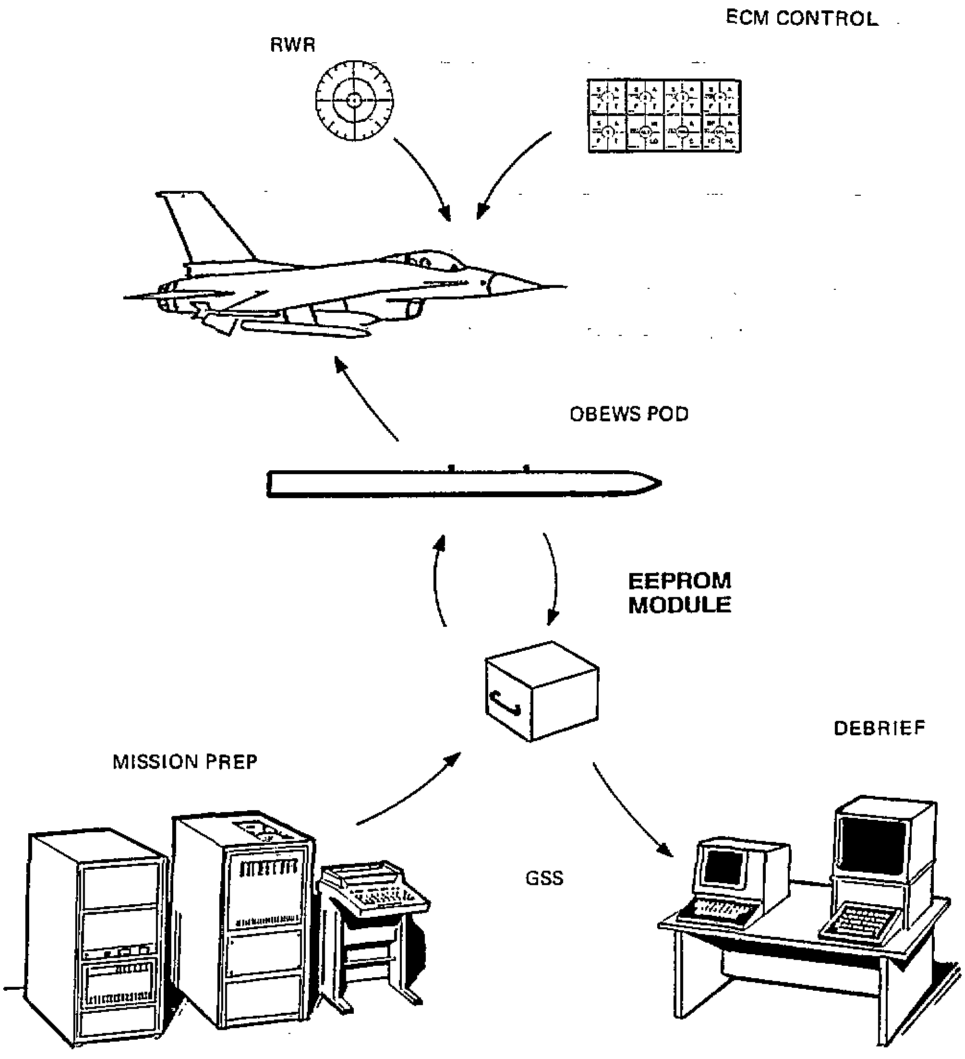

Figure 4. Onboard Electronic Warfare Simulator

On-Board Training capability for the AN/ALR-69 Radar Warning Receiver installed on F-16 fighter aircraft. The On-Board Training facilities will be retrofitted into existing airframes and existing RWR units. As shown in Figure 4, the OBEWS aircraft will carry an external underwing pod containing the On-Board Simulator (OBS) to manage a variety of simulation functions. The software in the ALR-69 is to be modified to accept and display simulated emitters. The ECM control panels are also monitored to determine the type of ECM being performed.

The On-Board Simulator runs a sophisticated threat emitter simulation to construct and maintain an EC threat environment. The simulation draws on a mission library containing simulated threat locations as well as threat emitter signal data and tactics data. The OBS also carries digital terrain mapping data for the gaming area defined for the aircraft mission. The OBS generates and updates a simulated EC environment consisting of active radiating threat emitters. The threats are activated and deactivated according to the range from the ownship to the threat as well as other criteria specific to each threat. The current ownship position and simulated threat locations are used to compute relative bearing and range from the ownship to the simulated threats. The digital terrain data is used to determine terrain masking or occulting between the ownship and the simulated threats. The simulated threats are stepped through operational modes according to the operational tactics data defined for each threat.

Once a simulated threat emitter has been activated and its operational mode and location have been defined, the On-Board Simulator generates signal identification data for the emitter and sends the data to the ALR-69 Radar Warning Receiver carried on the aircraft. The data messages are transmitted across the RWR's High Speed Data Bus and are handled by the RWR's bus receiver hardware.

Once inside the RWR, the simulated signal becomes part of the environment that is tracked by the RWR. Special OBEWS software in the RWR inserts the simulated signal into the tracking file maintained by the RWR to track radar signals in the environment. At this point the simulated signals become indistinguishable from actual radiating signals. The simulated signals are displayed on the RWR's display screen and trigger audio warning tones just like the actual signals. The simulated emitters display all the characteristics of real emitters; if the F-16 turns, the simulated emitters move on the display screen in the same direction and speed as the actual emitters.

The operation of OBEWS is transparent in the RWR. OBEWS does not interfere with the process of receiving, identifying and displaying actual emitter signals received from the outside environment. Indeed, in an OBEWS missions it should be impossible to distinguish actual emitters from simulated OBEWS emitters.

New software will be added to the RWR to handle the simulated emitters, while the existing RWR software remains virtually the same. The only additions to the existing operational software will be "hooks" to activate the special OBEWS routines. When OBEWS is not active the RWR will operate with no perceptible alterations.

The special RWR software receives simulated emitter data from the OBS via the RWR data bus, inserts the simulated signals into the RWR tracking file, and sends display data back to the OBS for recording. The OBEWS software requires 900 words of ROM program memory and 300 words of RAM data memory.

OBEWS involves other on-board devices as well. The controls of the ALE-40 Chaff/Flare dispenser and the ALQ-131 jammer are monitored to determine the electronic countermeasures being performed. This data is fed into the OBS to determine the ECM selected by the pilot. This information is then used in the Threat Reactions function to trigger ECCM responses in the simulated threats. Navigation data is monitored on the aircraft system data bus to provide ownship location information for calculating the relative positions of the ownship and the simulated threats.

Ground Support Station

The OBEWS Ground Support Station (GSS) provides mission support. The GSS enables wing personnel to specify an EC mission prior to the aircraft flight. The mission planner selects the threats to be included in the mission and specifies their location within the gaming area. The GSS then automatically assembles the mission data and stores it in a memory storage module that is carried to the aircraft and inserted into the OBS pod prior to the flight. While the aircraft is in flight this same storage module records flight and RWR threat data. During the post-mission briefing the pilot may review the flight on the sophisticated visual display shown in Figure 5. The display shows a 3-dimensional terrain map of the gaming area and the locations of the OBEWS threats within the area. The GSS uses the recorded flight data to plot the aircraft's flight path on the terrain map. The visual display also shows the status of active OBEWS threats at each point in time during the flight. A replica of the RWR display is also included on the display screen. The GSS reads the recorded RWR display data and re-creates the RWR display presented to the operator during the flight. Audio warning tones and indicator lamps recorded during the flight are also reproduced. This visual and audio display provides a complete replay of the RWR operation during the aircraft flight.

The pilot may thus review his entire mission. He can review threat emitter actions and the threat indications he observed on his RWR. He can review his own flight path and his use of evasive maneuvering and terrain masking to avoid the threats, as well as the effects of his ECM on the threats.

Aspects of On-Board Training

The OBEWS system illustrates a number of factors to be considered in any On-Board Training system. The most obvious is that it vastly increases the value of EC training with operational equipment. Any training mission over any geographical area can include an active EC component when OBEWS is operating. Simulated threat emitters may be scattered across any gaming area. EC training may be conducted over populated areas, over water, or in areas where radiating threat simulators are not available.

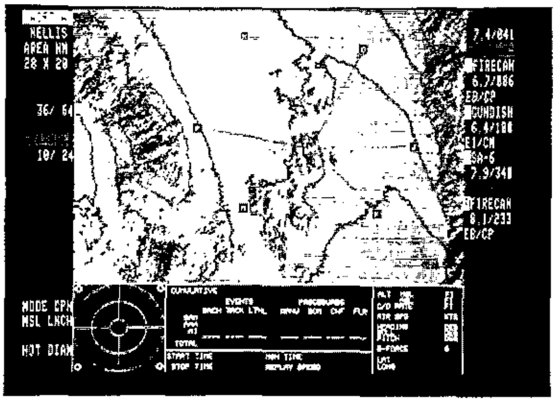

Photo Courtesy SAIC

Figure 5. GSS Debrief Display

System Configuration

OBEWS is configured as a system of interconnected devices in the aircraft and in the OBS pod. The OBT functions are controlled in the OBS processor, which gathers data, maintains the emitter simulation, and communicates with the RWR and ECM devices. The RWR and the ECM devices (or, rather, their control panels) are modified to communicate with the OBS processor and perform tasks required by OBEWS. This interconnected system represents the optimum configuration for flexibility and ability to perform complex operations. The dedicated OBS processor is designed to handle the major work load and to minimize the modification required in the aircraft devices. Communications between the devices are prompted by and routed through the OBT processor. Modifications and updates to the OBT would be performed primarily in the dedicated processor, minimizing the changes required to the aircraft devices.

The OBT system communication line would ideally be a dedicated system bus on which all devices could communicate. Such a bus is probably not available in most cases, particularly in retrofit applications where the wiring does not exist and many devices are not equipped for digital bus communication. A workable solution may be reached using existing buses and additional wiring. New aircraft are being built with general system buses using MIL-STD-1553 or similar protocols. It should be possible to connect the OBT processor and EC devices to this general bus for communication.

Role of Ground Support

Ground support plays an important part in OBEWS. The Ground Support System is required for planning and defining the simulated threat environment to be encountered during the training mission. And the addition of ground replay facilities greatly enhances the post-mission debriefing.

Training Effectiveness

On-Board Training could supplement both ground-based EC training simulators and actual training missions now in use. OBT can employ many of the techniques developed for ground-based trainers - high-density threat environments, threat behavior modelling, and recording functions for post-mission debriefing. In addition, OBT training missions would include the extra dimension in training realism found in actual flight missions. EC training missions are currently flown at training ranges using ground-based radar simulators to radiate simulated threat radar signals. The training utility of such radar simulators is very high, since they provide signals for EC training in an actual flight enviornment. On-Board Training would bring the same training effectiveness to geographical areas where actual radar simulators are not stationed. Aircrews could fly against EC threats in any geographical area where the OBT mission is programmed. In addition, an OBT mission can include a high-density threat environment not achievable with actual radiating radar simulators. And the OBT threats can include emitter types and signal parameters denied to radiating radar simulators for security reasons.

It is not likely that On-Board Training would ever effectively replace either ground-based trainers or training missions flown against radar simulators. Ground-based training simulators provide flexibility and instant replay facilities not possible during actual training missions. And ground-based trainers can be programmed to include equipment malfunctions, dangerous conditions, or geographical locations that are impossible for actual training missions. During training missions, radiating radar simulators can provide some training components that are difficult or impossible to match with On-Board Training; radar simulators can provide visual correlation with a physical target, and can provide human-controlled real-time counter-countermeasures in response to a training aircrew's ECM.

The level of realism in On-Board Training increases with greater complexity of the software involved. However, lower levels of realism may be appropriate for certain applications. As was noted above, the lowest level of complexity would involve simple threat indications on a warning display. Such indications would not exhibit any dynamic behavior, either in physical movement or in tactical behavior. This level of realism may be appropriate for basic trainers or for aircraft that do not engage the threats being simulated. A medium level of sophistication might involve simulated threats programmed for specific geographical locations, with simple tactical behavior and no terrain modelling. This medium level would be appropriate for aircraft following a fixed mission or without extensive ECM capabilities. The highest level of sophistication can include any number of simulated factors -- intelligent threat tactical behavior, terrain data for terrain masking, and so forth. This maximum realism is most appropriate for aircraft that actively engage or avoid the simulated threats -- the aircrew can train on tactics to avoid or defeat the threats.

Problems

Task Definition

On-Board Training poses a number of problems in design and execution. One basic problem involves task definition. As was noted previously, On-Board Training can be implemented on a number of levels of complexity. It is absolutely necessary at the outset of an OBT project to define the training requirements for the EC equipment and host vehicle. From these training requirements are derived the technical speifications, levels of complexity, and projected cost estimates. Without a rigorous task definition it is likely that the On-board Training functions will become over-specified and over-designed as more functions are added because they seem desirable. Design discipline must be exercised to insure that the OBT system does not become too large and complex. On the other hand, it is very wise to design the added functions with sufficient flexibility to permit alterations and additions to be made as a result of operational experience.

Safety of Flight

The addition of any device to an aircraft must involve safety of flight considerations, and On-Board Training equipment is no exception. If electronic hardware is to be added to the aircraft, the additional hardware must conform to standard requirements for electrical isolation and circuit protection. If the On-Board Trianing device is connected to any avionics system buses, the device must conform to communication protocols and bus protection schemes. If modifications are made to existing aircraft devices, the modification must not affect the reliability or safety of the devices.

Mechanical safety of flight requirements must also be fulfilled. If the On-Board Training devices are to be carried inboard, safety considerations will probably be limited to heat dissipation and cooling requirements for the additional equipment. If the additional equipment is to be carried in an external pod, the pod must undergo aerodynamic analysis and flight testing to certify its compatibility with the aircraft. The requirements for testing the On-Board Training pod may be reduced through the use of a previously-certified pod or external weapon structure. The analysis data for the existing pod or weapon would serve to support the certification of the new On-Board Training pod. In this case, the On-Board Training pod must maintain similar size, shape, weight, moments of inertia, and center of gravity as the original pod or weapon in order to retain certification.

Interaction with Normal Functions

Designers of On-Board Training systems must deal with problems of interaction with the normal functions of the host EC equipment. The OBT functions would typically operate by inserting additional threat data into the normal operating functions of the host EC equipment. These added functions must therefore work closely in conjunction with the normal operations without interfering with them or degrading the performance of the equipment. This non-interfering interaction is most difficult to achieve when existing equipment is being retrofitted with OBT capabilities. The original equipment software was not designed with "hooks" for extra OBT routines, and the design concept of the original equipment may not lend itself to the addition of OBT functions. In such cases it may be necessary to scale down the complexity of the OBT functions to make them compatible, or to use a more basic stimulation approach to inject OBT signals into the equipment. It is easier to design OBT functions into the host EC equipment from the beginning. Requirements for signal data and for software hooks can be defined during the stage where the equipment design is still flexible enough to fulfill such requests. It would even be desirable to include the essential hooks into equipment for which On-Board Training functions have not yet been defined. Future retrofitting of these functions would then be far easier to accomplish.

Resource Limitations

The inclusion of On-Board Training functions into a particular EC device may well run up against resource limitations in the device. The controlling processor may not have sufficient spare memory or processing time to handle OBT functions. And it may be argued that the operational functions of the EC equipment are so important that all resources should be dedicated to the basic operations and not shared with lesser functions such as On-Board Training. Limitations of time and memory resources are indeed a problem with older equipment. Older devices were typically designed with relatively little memory to begin with; and operational changes tend to consume the spare memory originally built into the system. The problem is less acute with modern systems that are designed with more processing power, more memory space, and large spare requirements. On-Board Training functions need not consume excessive amounts of spare resources, particularly if OBT is included in the original design.

Long-Term Maintenance

As with any embedded software, On-Board Training functions require long-term maintenance capabilities. Long-term maintenance is required when updates are made to the threat signal data or to the host EC equipment. The on-board OBT functions must have the flexibility to accept new threat signal data as new data becomes available. This data must be prepared at a ground station with OBT-update capabilities. This ground station requires a trained operator or at least self-documentig procedural instructions, as well as a mechanism for receiving and interpreting updated threat data. The OBT functions will probably require alteration if the operation of the host EC equipment is changed or updated. The OBT changes may be minor changes in data format or may involve major functional changes. In either case, a procedure must be in place to design and implement OBT changes in the long term.

On-Board Training on Land and Sea

The above considerations apply to EC equipment installed on land vehicles and ships as well as to the airborne equipment specifically described. For land-based systems, terrain masking would assume great importance in the ability to receive specific emitter signals. Dynamic models of signals from aircraft in flight would also pay a major role in a number of training applications.

Shipboard On-Board Training could become a major asset in EC training at sea. EC systems for ships can be designed to provide the high densities of emitters found in naval EC environments. On the other hand, terrain masking would not be required. Due to the long tours of duty of larger ships, many of the ground support functions would have to be performed aboard the ship instead of on the mainland.

20B5 Pierside Trainer

A partial implementation of On-Board Training concepts has already been developed in the Pierside Combat Systems Team Trainer, Device 20B5, built by AAI Corporation for the U.S. Navy.[1]

This trainer utilizes the actual on-board EC equipment aboard Navy ships docked in port between tours of duty, and incorporates the concept of stimulating actual operational EC equipment for training purposes. The EC equipment -- notably the AN/SLQ-32 Shipboard ESM Suite -- is stimulated with digital signal data so that EC operators may receive realistic EC training at their own equipment. The SLQ-32 computer is stimulated by an intelligent carry-on unit that plugs directly into the computer inputs. The carry-on units are controlled by a master computer housed in a mobile trailer sitting at pierside. This computer generates a simulated EC environment, defines signals and tactics for the simulated threats, and sends signal information to the carry-on units.

Conclusion

On-Board Training holds great promise for enhancing the training utility of operational EC equipment. Simulated emitters can be injected into EC equipment in forms ranging from simple stationary display symbols to complex dynamic threat models. Properly-designed On-Board Training functions will provide realism appropriate to the training situation in which they are placed. The design of an On-Board Training system requires careful attention to a number of factors ranging from definition of training requirements to specifying the system architecture and provisions for future modifications. When such a system is installed it can bring realistic EC training to many areas where it has not previously been available.

References

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Mr. ROLLIN L. OLSON is a Design Analyst in Electronic Combat Operations, Electronics Division of AAI Corporation. He is currently involved in the development of the OBEWS simulator. He has developed software simulations for radar emitters and EC equipment on the F-16 Electronic Warfare Training Device and the A-10 EW Simulator. His educational background includes graduate studies in computer science at Loyola College and in urban geography and history of technology at Johns Hopkins University.