Avionics and ECM System Integration on Military Aircraft

Salvatore Fucci* and Peter Zuzolo†
Fairchild Hiller Corporation, Farmingdale, N. Y.

To survive in the present and future hostile electronic environment, military aircraft will have to carry an ever increasing amount of countermeasures equipment. This paper reviews some of the major problems inherent in the design, development, and application of ECM (Electronic Countermeasures) equipment in high-performance aircraft. Areas covered include installation, aerodynamic and structural, electromagnetic interference and compatibility, special tests and plans, integration and enhancement, and coordination and management. To resolve the acute problem of conflicting requirements for improved aircraft performance vs large complex ECM installations, necessitates close coordination among all the engineering disciplines. The selection and installation of ECM equipment should be preceded by feasibility and any other tests required to determine how the equipment will function in its true aircraft environment. In the final analysis, the most demanding problem is the management effort required to coordinate the contributions from the various vendors and government agencies.

A. Introduction

To date, the F105D and F105F (Wild Weasel III) aircraft have been utilized for over 70% of the Air Force missions over North Viet Nam. When successive missions moved northward, the attacking aircraft were confronted with the most dense electronic defense in the history of EW (Electronic Warfare). As the enemy increased his defenses, immediate installation of ECM (Electronic Countermeasures) equipment on attacking aircraft became a critical requirement. Without the utilization of special electronics, continued attacks in northern sectors would have resulted in prohibitive losses.

On the F105 aircraft many new QRC (Quick Reaction Capability) type ECM systems had to be added in order for it to accomplish its role over the skies of North Viet Nam. These modifications were only achievable in a timely manner because of the team effort between avionics, aerodynamics, structures, weights, thermodynamics and the other engineering disciplines. Since the SEA (South East Asia) theater of operation has proved that ECM equipment is here to stay, the days of each engineering discipline working independently of each other are gone.

The purpose of this paper is to review some of the major problems inherent in the design, development, installation, and application of ECM equipment in military aircraft. Major problem areas to be discussed are 1) installation, 2) aerodynamic and structural, 3) electromagnetic interference and compatibility, 4) special tests and plans, 5) integration and enhancement, and 6) coordination and management.

B. Installation

The physical installation of added ECM systems is a major problem area. Space must be made available for the required electronics with many factors to be considered. These include satisfactory sensor, sensor housing, and equipment locations.

1. Sensors

Sensors can be considered the transducers of IR systems and the antennas of RF systems. Many sensors are required for all the ECM systems in addition to the sensors of the onboard avionics systems. The reduction of the total number of required sensors becomes essential because prime locations on a military high-performance aircraft are limited. In addition, many of the sensors desire the same location. The F105 aircraft requires 14 sensors for the onboard avionics and 55 sensors for the ECM systems reaching a total of 69 sensors (Fig. 1). A reduction approach must, therefore, be considered. Several reduction techniques are time sharing, switching, power division, diplex filtering, and duplex isolation. Location selection should be based on system priority, coverage, coupling, and system accuracy requirements.

The types of antennas that can be utilized offer a large variety. But considerations of frequency, polarization, coverage, power handling, bandwidth, aerodynamic, and other physical installation requirements generally limit the available types. The normal tendency for the aerodynamicist is to request a flush mounted antenna. This type of antenna has zero drag characteristics but has increased weight over the blade type antenna. The blade type antenna requires practically no space within the aircraft whereas the flush mounted antenna does. As a specific example, consider a typical antenna installation at L-band operation from 960 to 1220 MHz for IFF, TACAN and/or DME systems. A normal aircraft installation requires from two to four such antennas. A flush mounted AT-740/A

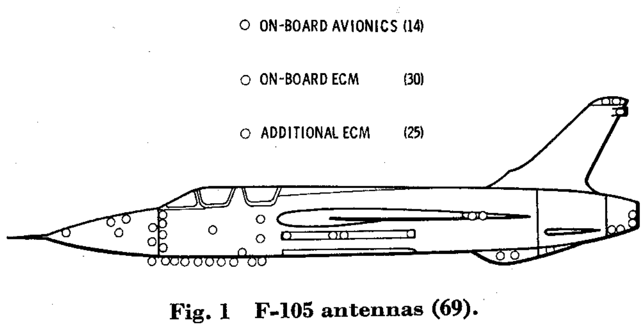

Fig. 1 F-105 antennas (69).

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* Chief, Electronic Systems.
† Group Engineer, EM/ECM Systems.

annular slot type antenna weighs from 12 to 21 oz and has an internal volume from 30 to 32 cubic inches, dependent upon the manufacturer. A blade antenna such as the AT-741/A for the Mach 1 to 2 region weighs 6.4 oz. For the Mach 3 region, the AS-1448/A blade antenna weighs 7.7 oz (Fig. 2). From the electromagnetic aspect the blade antennas are preferred since they have better VSWR matching and radiation coverage characteristics.

It can be seen then, that dependent upon the particular application a 30–65% weight savings plus a minimum of 30 cubic inch volume can be saved per antenna. The tradeoff and decision can only be judiciously made as a team effort between the proper engineering disciplines.

2. Sensor Housings

Sensor housings are defined as irdomes for IR systems and radomes for RF systems. Some system antennas cannot be flush mounted or blade types. These antennas must be housed in radome fairings to minimize the deleterious aerodynamic effects on aircraft performance (Fig. 3). From an electromagnetic viewpoint, the radome must provide maximum transmission of EM energy through it without distortion.

One parameter for optimizing transmission is the incidence angle of the EM energy. An optimum shape for normal incidence angle is a hemispherical shape with the center at the antenna. Unless the housing is very small, this shape can only be utilized for low-performance aircraft. A compromise shape on high-performance aircraft must be reached by the close interwork of the EM and aerodynamic engineering disciplines.

Other parameters for optimizing transmission are the dielectric constant and thickness of the radome material. A proper choice can only be made by the trade offs made by the EM, thermodynamic, structural, mechanical and weights engineering personnel.

As opposed to the onboard avionics systems of a military aircraft which operates over narrow frequency bands, the ECM systems must generally operate over wide frequency bands. Several solutions for this aspect have already been implemented. A three-layer A-sandwich type construction is described in Ref. 1 and a single-layer construction is described in Ref. 2.

3. Equipment

For avionics and ECM equipment locations on new aircraft, these considerations are integrated into the early design phases. For modification to existing aircraft, ingenious techniques must be conceived. These ideas must again be accomplished with a close working relationship of all the engineering disciplines concerned. On the F105 airdraft, a pylon stores station was released for weapons instead of an ECM pod which should not be dropped anyway. Working with aerodynamic and structural engineers the ECM pod was in effect cut in half and each half placed above the bomb bay doors as a blister (Fig. 4).

Another idea was the extension of the area aft of the canopy into the vertical tail base. This saddle back modification will be used to house additional avionics equipment. Blisters will also be utilized on each side of the aft fuselage station to house additional ECM equipment. The equipment location

TYPE	WEIGHT (OZ.)	DRAG	SPEED	VOLUME (IN^3)
AT-741/A	6.4	X	MACH 1-2	0
AS-1448/A	7.7	X	MACH 3	0
AT-740/A	12 - 21	0	X	30 - 32

Fig. 2 IFF/Tacan/DME antennas L-Band frequencies (960–1220 MHz).

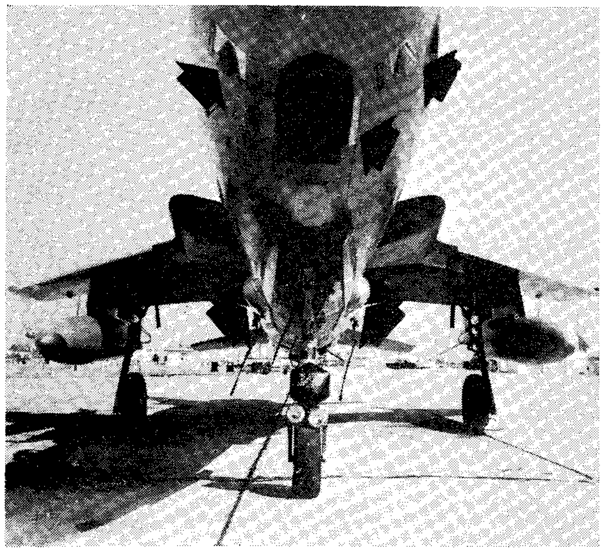

Fig. 3 Radomes.

choice must also consider ease of installation, modification, maintainability and repair, and minimum RF cable runs between the sensors and the equipment. The short cable runs are required to minimize cable losses and system delay times. The cockpit configuration must be considered in order to give the pilot an optimal display. Each control and/or indicator must be located for adjustment, accessibility and visual acquisition.

C. Aerodynamic and Structural

The effect of ECM system installations on aircraft performance must be minimized. As described in Sec. B, the antenna and radome housings may result in serious degradation to aircraft performance. The drag considerations, the structural, the weights and balance considerations, the flutter and vibration considerations must all be integrated aspects of the over-all problem.

The location of external antennas and blisters must all be considered in the light of possible air inlet duct disturbances and shock wave generation. The addition of each electronic subsystem requires judicious tradeoffs between functional mission requirements and aircraft performance.

Aerodynamic tests were conducted to determine the incremental drag caused by the blister type housing (Ref. 3). The results indicate that drag is increased by approximately 10 counts ($0.0010C_D$) at Mach numbers below 0.85 and by approximately 20 counts above 1.1 Mach number (Fig. 5).

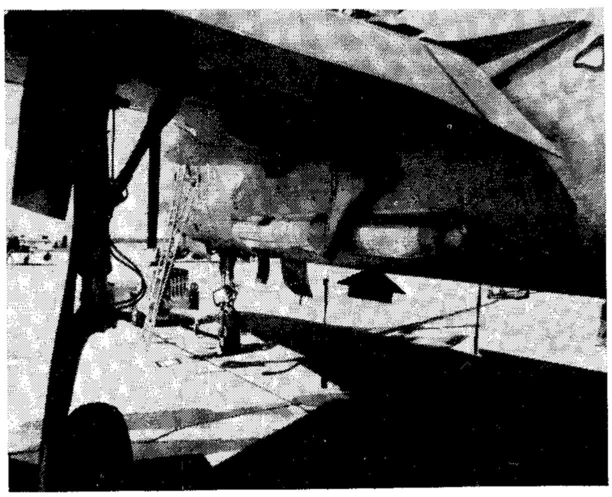

Fig. 4 . Blister.

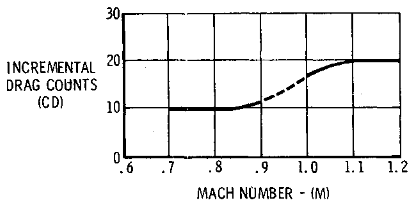

Fig. 5 Blister drag.

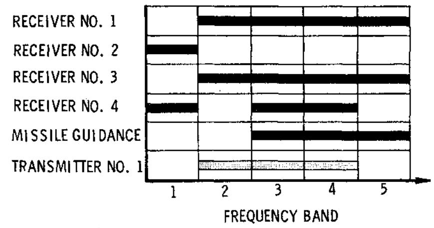

Fig. 6 ECM system coverages.

The actual drag increment for carrying this type blister is less than the incremental data shown since this data does not take into account the drag that would be caused by the equivalent type ECM pod mounted on a pylon stores station.

The other sensor housings described produce a 6 to 8 drag count increment. This aerodynamic information must be converted to operational aircraft performance. In general, a 1% decrease in range of the F105 can be caused by an additional drag count of 4, an additional weight of 400 lb or a combination of the two. This type of tradeoff must be conducted in the over-all mission requirements.

D. Electromagnetic Interference and Compatibility

The minimal ECM systems include many highly sensitive receivers which must operate in the same frequency range as jamming transmitters that radiate tremendous amounts of power (Fig. 6). Each ECM system must be operational and perform its function without deteriorating the performance of the other ECM systems and the normal on-board avionics such as fire control radar, navigational radar and CNI systems.

Several approaches have been utilized to minimize EMI (Electromagnetic Interference) and insure compatibility of active radiating systems on passive receiving systems. They include 1) blanking, 2) filters, 3) antenna isolation, and 4) determination of power levels. Viewing active systems from the passive viewpoint, compatibility has been achieved by 1) leading edge tracking (self-blanking), 2) coincidence unblanking, and 3) determination of system delays.

E. Special Tests and Plans

Quite often some of the most sophisticated ECM developments which show great promise in the laboratory have to be discarded after time consuming and expensive flight tests because of the severe limitations imposed when these equipments are installed on military aircraft. Invariably the vendor developing the ECM equipment takes one look at the aircraft for which the equipment is intended and assumes that choice locations will be reserved for his particular ECM system. He gives little or no consideration, or is not in a position to quantitatively determine how the added equipment will affect the performance of other systems already installed on the aircraft. For the previous reasons, in selecting and installing ECM systems for military aircraft, feasibility and/or special tests are indispensable during the early stages of analysis and development. These tests include:

1) Comprehensive radiation pattern tests of all required antennas under various store and armament conditions.

2) Selection and tests of transmission lines and connectors. It is not always possible to locate transmitters close to preferred antenna locations. Analysis of degradation of performance caused by cable attenuation must be judiciously evaluated.

3) Analysis, computation and measurement of time delays between receipt of a target signal and the transmission of a compromising signal from the aircraft. To be effective, jammers require delays in the order of nanoseconds. Delays in electronic equipment, connectors, free space radiation and cables must all be considered. The possibility of sneak paths should be thoroughly investigated.

4) Computation and measurement of isolation and/or coupling between antennas at proposed locations. The coupling problem is especially acute in the case of ECM when receiving antennas sensitive to very small signals must work in proximity to high-power jammers.

5) Flight Test Plan—The flight testing of ECM systems is unique in that it usually requires special sites and facilities. Since the facilities are few in number and are normally run by the government for only the highest priority projects, the time that can be allocated to any one program is at a premium. The preparation of a practical, minimal but adequate Flight Test Plan is paramount to a satisfactory and timely evaluation of ECM systems. Early and close coordination must be maintained between the contractor and the operating personnel of the ground sites which will be utilized. Efficient use of allocated flight test time is essential! Each additional hour spent on reviewing and updating the plan will save days, if not weeks, of frustration because of delays which can be attributed to inadequate planning. Moreover, by judicious use of selected instrumentation which can be installed in the aircraft, data obtained from the ground sites could be supplemented with data which can be recorded in flight.

F. Integration and Enhancement

The interface between all the electronic systems must be integrated to insure proper and accurate operation of all the systems whether operating independently or as an integral unit. Each added ECM system is considered as part of the over-all weapons systems and integrated with the other ECM systems as well as the other onboard avionics systems. This interface integration is then carried one step further than just obtaining compatibility. The information or signals from one system must be utilized to enhance the performance of other systems. When not utilized for enhancement, the signals can be used for correlation of information. Passive systems can also be utilized for other functions, such as 1) control and direct missiles, 2) control and direct jammers, and 3) program decoys, chaff and flare dispensers. To conserve weight and space, redundancy must be minimized to only that which is essential to the mission. The general tendency is to go overboard and overload the aircraft with ECM systems. The role of the aircraft as a tactical fighter-bomber or as an air superiority fighter-fighter must be considered in determining the minimum amount of ECM systems required.

Another system engineering aspect that must be considered for active ECM systems is the direction and/or level of power required. To optimize system performance in lieu of using higher power outputs indiscriminately, for more effective J/S (jamming to signal) ratio, use the higher power only where the radar cross section of the aircraft is the largest. Also instead of radiating the power omnidirectionally or in each quadrant, program the active jammers so that the radiation is from the antennas in the direction from where the threat is present. These techniques insure that the effective power density is not diluted.

G. Coordination and Management

During the past few years, the gradual evolution of an effective ECM system on military aircraft has progressed steadily. Step by step improvements have been made by different vendors working for different government agencies. Primarily because of security, there has been little, if any, exchange of information between organizations. The situation has been aggravated by the ever-changing flexible requirements due to the nature of electronics warfare. Moreover, in the highly competitive ECM field, electronic contractors are very reluctant to provide information about their systems to other electronic contractors who may be their competitors. In the final analysis, the most complex problem in the development of ECM systems is the management effort required to coordinate the contributions from the various vendors and government agencies. The coordinator can insure that only necessary and sufficient information is interchanged between electronics contractors to achieve solutions to all the problems. This management and coordination effort can also insure that commonality and cost effectiveness are always prime considerations. Because of conflicting installation requirements, in most cases the job of developing a practical ECM system can best be done by the prime aircraft manufacturer acting in the role of coordinator.

H. Summary and Recommendations

1) To survive in the present and future hostile electronic environment, military aircraft will have to carry an ever increasing amount of countermeasures equipment.

2) To resolve the acute problem of conflicting requirements for improved aircraft performance vs large complex ECM installations, necessitates close coordination amongst all the engineering disciplines. In the case of the F-105, the necessary modifications were accomplished on time only because of the strong well-integrated team effort of aerodynamic, structural, thermodynamic, installatiion, and avionics personnel.

3) For new developments the selection and installation of ECM equipments should be preceded by feasibility and many other tests required to determine how the equipment will function in its true aircraft environment. This should include radiation patterns, transmission lines, time delays, and isolation or coupling.

4) The preparation of a practical, realistic, minimal but adequate Flight Test Plan is paramount to a satisfactory and timely evaluation of ECM systems.

5) Some of the techniques utilized to maintain compatibility between active and passive systems include a) isolation and/or sharing of antennas, b) leading edge tracking, c) coincidence blanking and time sharing, and d) selection and design of system delays.

6) Use of ECM pods on conventional pylons denies the aircraft use of this station for a store or to carry fuel. Under development is the use of a blister on either side of the aircraft to house electronic equipment normally installed in the pod.

7) A conventional ECM system will require the integration of several subsystems to be supplied by many different vendors usually working independently of one another, or for different government agencies. Depending on the specific mission requirements, different aircraft will require different levels of ECM equipment. Tradeoffs are inevitable. In order to develop a satisfactory ECM system without serious degradation of aircraft performance, management of the program as well as responsibility and authority to control the program should be vested in a single government agency or contractor.

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