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Integration of Defensive Aids

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ABSTRACT

This paper, arising from project and research work at DERA UK, considers the application of, and options and possibilities for, the integration of electronic combat (EC) equipments, specifically defensive aids systems (DAS) into air vehicles, focusing upon the problems and issues of retrofit and upgrade programmes.

The paper describes the threat to air platforms, citing both intense conflict and peace - keeping scenarios, and introduces the potential advantages of fully integrated defensive aids in terms of aircraft survivability, and in contributing towards overall situational awareness.

The retrofit and integration of defensive aids into an in-service aircraft present some challenging problems. The level of integration is a determinant of the cost and complexity of the programme. The choices range from the basic mechanical integration of separate subsystems; through the integration of a defensive aids system within itself; the integration of the system into existing cockpit displays and controls and into other avionic systems; to the ultimate level of integration in which the defensive aids become an intimate part of the flight avionics suite.

The style of avionics and cockpit controls present in the target aircraft is another key factor in the cost and complexity of the upgrade task. Retrofit into well integrated avionics, and multifunction displays, implies that software modification, and hence re-certification, will represent a major part of the integration task.

The paper describes the features of integration which may be achieved at the different integration levels. A high level of integration is needed to facilitate data fusion, an important contributor to situational awareness. The paper discusses the structure of data fusion implementations, and the accompanying problems.

Modifications and additions to ground support elements are identified as essential to the success of the retrofit or upgrade programme as a whole.

The desired level of EC integration will be driven by the customer's specification, which in turn is scoped by his understanding of the detailed issues in integration: the features and facilities which are both feasible and operationally useful. The risk exists that integration features may be sacrificed to contain costs, resulting in fits of expensive and capable items of kit which cannot be used operationally to their full potential.

1. INTRODUCTION

1.1 The Air Environment

Current military air platforms are required to operate in an environment which can contain a high level of threat. Anti-air threat systems have proliferated, diversified and generally improved in effectiveness in recent years. Anti-air systems are in the field which make use of wide segments of the electromagnetic spectrum, from radio frequencies, through infra red to the visible bands. Anti-aircraft missile guidance methods range from passive infrared seeking, through semi-active systems in which missile seekers lock to illumination of the target from the launch point or some associated system, to active radio frequency seekers. Some systems rely in whole or in part upon manual guidance from the firing post.

Threat types span the long range surface or air - launched missiles, through vehicle - mounted ground mobile missile or gun systems, to man-portable air defence missile systems (MANPADS).

Major conflicts could see the deployment of a wide range of anti-air threats. However, there is increasing emphasis within NATO on the lower intensity peace keeping or policing actions - operations other than war. In these scenarios the MANPADS and gun systems are likely to represent the major threat.

1.2 Platform Self Protection

In the face of an increasing level of threat to air platforms, nations have responded, or are likely to respond, by retrofitting or upgrading elements of defensive aids systems in their aircraft.

A **Defensive Aids System** (DAS) comprises a suite of sensors, effectors, algorithms and human-machine interfaces which seeks to enhance the survivability of a military platform or formation. A DAS seeks to combine and present information from a range of sensors to provide situational awareness, and timely warning of threats. It seeks to identify, characterise and prioritise threats in order to command the most effective use of countermeasure strategies including avoidance, tactical manoeuvre, emission control, radio frequency or electro-optic countermeasures and shoot-back systems.

Defensive aids systems are typically made up of a selection of sensing and effecting elements.

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Additionally, defensive aids systems may make use of, or further process information from, other sensors such as radar, imaging and identification systems, from intelligence sources and from off-board sources.

A DAS may be implemented in a distributed form to protect a fleet or formation.

1.3 Defensive Aids in the Context of Electronic Combat

The term **"electronic combat" (EC)** covers the non-image-delivering military use of the electromagnetic spectrum. It includes all aspects of denying, confusing or deceiving the enemy's use of the EM spectrum, both imaging and non-imaging, and the exploitation of his use of the EM spectrum to one's own advantage. Electronic Combat covers passive sensing and geolocation of threats, defensive RF & EO sensing, alerting and countermeasure systems, RF and EO stealth, directed energy weapons and all types of jamming system.

Defensive aids sensor and effector systems can provide many of the elements of an airborne EC capability.

1.4 EC Systems and EC Systems Integration

The traditional DAS concept is focused upon detecting and countering immediate threats from missiles and guns - when the platform is under attack, the first priority is survival, and equipment designs have reflected this imperative.

The systems view of EC for platform self-protection adopts a three layered approach toward optimising platform survivability:

a) Threat avoidance: Traditionally this form of protection has been achieved through mission planning and intelligence. In flight, detection by the enemy is minimised by the use of terrain cover through low flying, and by control of the exposed platform signature. *Integrated* EC systems can offer long range passive sensing of pop-up threats, permitting in-flight mission re-planning.

b) Minimising Danger: The platform can attempt to confuse or suppress enemy surveillance and acquisition systems, or reduce the ability of the threat to successfully engage by choice of altitude, or by flying tactics. Where it is not possible to avoid a threat, nor to suppress detection, then it is feasible to select the most favourable approach geometry, to minimise exposure and to deny engagement opportunities to the enemy.

c) Close in defence: The defensive layer is invoked only if a threat is engaging the platform. Here the EC components providing close-in threat warning cue countermeasure effectors which attack some aspect of the incoming threat's ability to locate or damage the platform.

A common thread in all three layers is the need for situation awareness. The design of a DAS or an EC system fit to an aircraft must be biased firstly towards providing a good general observational and alerting capability relating to threats, secondly towards offering a range of countermeasures. This is because, without knowledge and situational awareness, countermeasures as separate entities are of little use.

EC systems integration, encompassing all sources of information available to the platform, offers the *potential* for long range situation awareness by forming a comprehensive picture of threat positions and identities.

2. LEVELS OF INTEGRATION

The level of integration of a new or upgraded defensive aids system, is a determinant of the cost and complexity of a retrofit programme. The choices range from: (i) the basic mechanical integration of separate subsystems, each complete with its own set of displays and controls; through (ii) the integration of a defensive aids system within itself, including some common means of display and control; (iii) the integration of the system into existing cockpit displays and controls alongside integration with other avionic systems such as communications, weapons and weapon aiming and to terrain databases; to (iv) the ultimate level of integration in which the defensive aids become an intimate part of the flight avionics suite, whether in a federated or integrated modular avionic architecture.

2.1 Basic Mechanical and Electrical Integration

The basic mechanical integration of new units or sub-units, represents the simplest and cheapest approach to DAS retrofit. Some self-contained sensor or effector unit is procured from a subcontractor. The task of the systems integrator is then one of mechanical integration of the main unit or units, its sensor or effector heads (which will usually require mounting on or through the airframe, that is, *apertures* must be provided), its crew controls and displays and of cabling between sub-units.

The integrator must arrange for the provision of power and typically a few electrical or electronic signals containing for example navigational data and platform velocity. The total effect of the retrofit must be assessed in terms of the total platform weight, aerodynamic drag due to external fitting, and changes to centre of gravity and moments of inertia.

The greatest challenges lie firstly in the area of crew controls and displays. Units need to be positioned within sight and reach of the crew, and suitable cockpit space is typically hard to find.

The second critical area is in the positioning of sensing or effecting apertures. External space is often very limited, particularly on small airframes, and all prime locations will often be occupied by existing systems. DAS sensors and effectors demand clear fields of regard or specific directions of fire, with numerous individual constraints.

Optimal placement of sensors and effectors requires extensive study work covering not only the performance of the system in question, but also its effects on other systems, on flight safety, and whole platform performance.

Significant costs are incurred in the area of flight safety testing and re-certification following such a retrofit programme.

This style of DAS integration may deliver a total system in which the individual subsystems are poorly linked and integrated, both with one another and with other relevant aircraft systems. Some limited integration features, for example permitting a sensor to directly trigger a countermeasure, might be realised. In the main, however, sensor data is merely made available in some way to the aircrew who then have to perform cognitive and decision processes, and initiate correct and timely countermeasure responses. Furthermore, these data are typically not presented in a centralised and optimised form, but distributed among a number of display units.

The situation described could evolve from the procurement and installation of add-on systems on the basis of operational need; but this to a degree is inevitable when global operational scenarios rapidly change and new and unexpected threats arise and demand urgent solutions. Of course, this situation does not apply to DAS alone, but to a cross section of avionic systems and functions. The result, apart from the difficulties that aircrews could have in operating such platforms effectively, could be a proliferation of build standards. If a fleet of aircraft is to remain in service for a significant length of time, then the ever increasing cost of maintenance would eventually dictate some sort of rationalisation programme to harmonise build standards across the fleet.

2.2 Integrated Defensive Aids System

An **Integrated Defensive Aids System** (IDAS) typically comprises a suite of sensors and countermeasures designed to offer its host platform a range of self protection options, against a variety of threat types.

An IDAS is integrated within itself, and will typically be procured through a single subcontractor. There will be some central integration function, a DAS control element, which might be realised in a discrete unit or sub-unit, or embedded in some other part of the system. Sub-units will be linked by some sort of communications bus. The system will be provided with a common display and control unit or function.

The DAS control element should act as an automatic integration engine, servicing common DAS displays and controls, and assisting the pilot's decision making by suggesting, or even implementing, countermeasures.

It should provide data formatting and conversions, association of threats declared by various sensors, kinematic data fusion, resolution of any conflicting threat identifications, overall threat prioritisation, and the trigger for appropriate countermeasure deployment. It should also provide a common channel for DAS data logging, common DAS status and error reporting, and a common point for loading DAS mission software.

Additionally, the DAS control element should provide the link between the DAS and the aircraft avionics. It should accept and distribute basic data from the aircraft navigation system such as aircraft position, velocity and heading, and data such as time reference and status.

The main benefit of an IDAS is that a central control unit can hold a library or database of integrated countermeasure responses to threats. In un-integrated DAS implementations each warner - countermeasure group would hold its own such library. In an integrated solution there is scope for better identification of threats, better tracking of threats and hence improved application of countermeasures.

The integrated system should be able to estimate the lethality of threats and prioritise them for DAS countermeasure response, then select the most appropriate countermeasure tactic against a detected threat (where such tactics could include a recommendation for manoeuvre). It should be able to allow for uncertainties in identification and deploy counters to a number of likely threats simultaneously. It should also be able to counter mixed mode threats, as well as truly multispectral threats. It must arbitrate the needs of DAS sub-units; effective sensing, for example, may require that effectors be silenced or inhibited periodically to allow for look-through, with minimum disruption to the countermeasure effect. Lastly, it must be able to decide or recommend when to cease countering a threat.

An IDAS should, by virtue of its architecture, offer the growth potential to cope with a wider range of sensor and countermeasure types.

The task of the platform systems integrator is similar to that in 2.1 above. There will be considerations of the supply of power and signals, of platform weight, centre of gravity, and aerodynamics, of placement of sensors and effectors, and of crew controls and displays. The costs of flight safety testing and re-certification following an IDAS retrofit programme will be significant, but probably less overall than if the sub-units of the IDAS had been retrofitted in separate programmes.

The placing of an IDAS crew control and display unit may be more or less difficult than the task in 2.1 above: only one unit must be accommodated, but it is likely to be larger and more complex than any of the several separate units it replaces.

2.3 IDAS with Avionics Integration

This third level of integration represents a major step towards full integration between the individual elements of which the DAS is comprised, and between the DAS as an overall entity and the aircraft avionics system.

The main advances over the IDAS concept of section 2.2 are:

a) Integration with cockpit multifunction displays;

b) Integration with avionic systems, sensors and databases.

2.3.1 Display Integration

Multifunction display and control units are present in the current generation of civil and military aircraft. They offer large TV-style displays which can be programmed to represent a variety of instrument types, as well as maps or map-style displays for piloting, navigation and targeting. They are typically menu structured allowing the aircrew to navigate through a wide range of display content and formats. They offer programmable key functions, through touch-screen technologies, for crew interaction. Audio tone and voice warnings, and even voice entry of data and commands, are sometimes offered in addition.

Such displays are driven by powerful computing elements which *in principle* offer a simple means of integrating new data type and display formats. It is important at this level of integration, that crew interaction with the integrated DAS be realised through the aircraft multifunction HMI and its associated processing capability.

A major adaptation will be in the area of display formats. DAS formats should both add to and modify display pages used for piloting, navigation, communications, mission planning and weapon control. Typical formats would include:

a) Spoke - style displays indicating the bearing and priority of each threat, and the status of countermeasure deployment. All IDAS sensors producing threat bearing and/or range indications, should share this one display through an underlying data fusion process;

b) Tabular text and/or graphic displays for the monitoring or set-up of operational parameters, or parameters required for trials, evaluation or acceptance testing as required by the elements of the IDAS;

c) Map type displays with threats shown at their estimated positions. If digital or digitised maps are available then these should form the underlay for map - style displays. Tracks which have converged in range, can be shown at their estimated positions relative to the map. Bearing-only tracks, representing high priority threats, may be displayed as spokes relative to own ship position on the map.

   A useful addition on this type of display is the overlay of threat lethal zones and/or threat detection zones. It is important that DAS information be available for display on the map - style display pages which are used for piloting, navigation, route planning etc., and those used for display of the air picture as received via a communications medium. In this way the current threat situation can be used by the crew to plan avoidance and adjust flight plans;

d) There should be means for an IDAS recommendation for tactical manoeuvre to be displayed.

The adaptations described above represent the ideal. However, the re-programming of multifunction displays can be an expensive exercise. The risk exists that when cost trade-offs are made, the retrofit implementation may support only a few additional DAS - specific display pages, with little or no integration of DAS - derived information with that from other sensors, communications, or mission data.

The second cost-related risk is the omission of adequate display of DAS - derived information on screens used for piloting and flight planning. The positions of threats known at the time of mission planning may be seen by the IDAS sensor suite to have changed; the omission of such important data from flight planning screens would represent a serious gulf between capability and realisation.

2.3.2 Avionics Integration

An IDAS can potentially make use of threat and supporting data coming from any of the following avionic functions:

a) on board targeting sensors such as radar and infrared search and track;

b) pilot visual designation;

c) pre-mission database information on the locations of known threats;

d) geographic or terrain databases offering, for example, intervisibility plots;

e) off board threat data arriving via some communications system.

The IDAS should be capable of responding to commands from the mission avionics (but which may originate from the pilot), for example:

a) to ignore a particular threat;

b) to invoke a particular style of countermeasure;

c) to silence emitters.

The effective use of avionic data, and the means of acting upon commands, presents a challenge to the IDAS subcontractor particularly in the area of system test and acceptance. The more deeply embedded the IDAS becomes, in the mission avionic system, the harder its becomes to prove its functionality as a separate entity.

The avionics or mission system can potentially make use of DAS - sensed data, and offer capabilities such as:

a) forming a (data fused) air and surface picture from all available sources including IDAS - sensed data;
b) aligning optical or thermal sights to an IDAS - detected threat or target;
c) aligning a search or tracking radar to an IDAS - detected threat or target;
d) aiming a designator or weapon against an IDAS - detected threat or target;
e) acting upon an IDAS recommendation to silence some or all emitters;
f) communicating IDAS data off board.

IDAS data collected in flight should be logged, and this data log integrated with any other mission level data logging facility.

IDAS training features should be integrated with any more general on-board training suite.

The mission system should perform the high level control and tasking of the IDAS. It must direct decisions on how to deal with some particular threat. This could involve mission replanning, weapons assignment, tactical advice, emission control, or an IDAS response. The final arbiter should in most cases be the pilot - the system, however, must be able to offer the most effective options, and act upon his or her command.

The platform systems integrator must provide data to the IDAS in a timely fashion, and provide the enhanced functions and capabilities.

It may be simplest to give the IDAS access to a suitable avionic systems bus, if such exists. However, it is inevitable that considerable changes must be made to existing avionic systems software, and that some changes will impact upon flight-safety-critical functions, implying considerable costs in re-certification of the software suite as a whole.

2.3.3 Suitability for Retrofit or Upgrade

It is difficult to implement the features of integration described above, as part of a DAS retrofit or upgrade programme. The level of difficulty, and hence expense, increases as the number and depth of integration features increase.

Practically, such a level of upgrade is best tackled as part of a larger aircraft upgrade or refit programme. In this way the considerable cost of flight safety testing and re-certification may be spread across a number of system improvements.

2.4 DAS Integrated within a Federated or Modular Avionic System

This represents the ultimate potential level of integration of DAS and avionics, in which the DAS is no longer identifiable as a separate entity. DAS sensors should operate alongside other sensors such as radars and infrared search and track, as an integrated sensor suite offering the aircraft a wide coverage of the electromagnetic spectrum, with both active and passive capability. DAS effectors should operate alongside other effectors, such as weapon systems, offering a variety of means for both conducting and surviving a mission. A central controlling and scheduling function should interact with the sensors, effectors and crew, as well as with other avionic systems such as communications and navigation, and mission databases, to command responses to the sensed environment.

2.4.1 Federated System

A federated avionic system is one in which subsystems, central computing elements, and display and control units are linked together by some sort of communications bus, permitting exchange of both data and commands. One unit will act as a master controller regulating bus activity. The units connected to the bus will often be of widely varying types, procured from many different sources, and performing unique functions. Mil Standard 1553 has been a common choice of bus standard, although the bandwidth it offers is limited. In many realisations of federated architectures, several separate busses connect major subsystems together, with a few special units providing gateways between these separate busses.

2.4.2 Integrated Modular Avionics (IMA)

An IMA system is one in which all, or at least a major part, of the signal and data processing functions in the aircraft are implemented in a core system comprising a set of standard data processing and signal processing modules.

The main advantages of this approach arise from the commonality and replaceability of modules, reducing spares holding and maintenance requirements. An IMA should allow for additional or upgraded modules to be inserted into the system with no other hardware or software modification. If reconfigurability is built in to the IMA architecture, then the aircraft can be equipped with "spare" hardware capacity, allowing for module failure to be circumvented and thus improving the availability of the aircraft as a whole.

There are several possible styles of IMA, and IMA concepts vary in scope. A core IMA might consist only of data processing or general computing elements.

A more ambitious IMA implementation might include high speed signal processing elements, and the most advanced concepts would also include high speed digitisers, and programmable ASIC hardware to take direct input from sensors of many types.

2.4.3 Level of Integration

Federated and IMA architectures are often marketed as offering an inherently high level of integration, however, this is not the case. Integration always costs time, effort and money; these architectures certainly *facilitate* advanced integration, but the cheapest solution may offer minimal functionality. The traditional division of industry into subsystem specialists has tended to offer the system integrator with a series of independent subsystem packages, even when these are implemented within a highly integrated architecture. If an integrated system solution is to emerge, then the systems integrator needs deep involvement in every subsystem, from the stage of initial specification, onwards.

The *goals* of EC integration are the same as those listed in 2.3.1 and 2.3.2, however, the means of achieving these goals can be better managed:

a) Centralisation of the plan formation, scheduling and decision making functions of all the avionic subsystems, avoiding conflicting and overlapping decisions which could arise from subsystems controlled locally. This centralisation also offers better control of the pilot's workload, and communications channel capacity.

b) Multi-functionality of sensor and effector assets can be implemented more readily. The problem of time scheduling the use of shared assets can be tackled centrally.

2.4.4 Retrofit Issues

Advanced federated, and IMA avionic implementations are too new for practical problems of retrofit to have emerged, however, some of the likely key issues may be anticipated:

a) Even the smallest change to a federated system's bus traffic, or an IMA system's application code, will involve costly system-level test and verification. The systems integrator must maintain a comprehensive emulation test bed, with facilities for monitoring bus, processor and memory loads, latencies and areas of real time criticality.

b) In the context of multi-functional sensor and effector assets, any upgrade to a single functional area must be assessed for its impact on all other functions which that sensor or effector has to perform.

3. INSTALLED PERFORMANCE

The mechanical integration of retrofitted DAS elements, in particular of sensor and effector apertures, can be costly and may limit the performance of systems.

Effector aperture placement, can suffer from the problems of airframe obscuration.

The placement of radio frequency receiver apertures in particular, also of electro-optic apertures, can pose considerable problems due to the disruption of signals arising from airframe shadowing and reflections.

These difficulties imply a need for thorough and comprehensive flight trialing of installed performance parameters.

The issue of installed performance also has the potential to cause contractual difficulties, with a blurring of the responsibility for achieving contracted performance parameters, between the DAS subsystem contractor and the airframe prime.

4. LOGICAL INTEGRATION

All subsystems which react to information require to be fed with concise and reliable inputs. The aircrew is arguably the most important user of, and reactor to, information. A vital function of an integrated DAS should be to remove confusion and information overload from the pilot.

Sensor and other data sources must be combined, compressed and presented. This aspect of integration, tackling the logical integration of the data offerings of retrofitted kit, should be given consideration in any upgrade programme. The risk exists, that as a result of cost trade-offs, data fusion may be dismissed as too difficult, too costly and of insufficient importance, or at best tackled superficially.

4.1 Data Fusion

Data fusion offers a family of tools and approaches to the systems integration problem outlined above.

The complex field of data fusion is typically divided into a number of levels, representing stages in the chain of processing of data.. Table 1 below describes the levels of the JDL-97 five-layer model of data fusion processes (pre-processing, object refinement, situation refinement, impact assessment and process refinement), and the similar OODR model (Observe, Orient, Decide, React), which map well onto the problems of integrating DAS sensors and effectors both within themselves and with other aircraft sensors and information sources:

Fusion at level 1 is firstly concerned with the optimal estimation of target kinematics. Typically this involves combination of measured data from more than one sensor source.

An IDAS will typically include one powerful long range sensor, a radar warner or ESM, able to locate and identify threats. There is a key role for data fusion at level 1 even if a radar warner/ESM is the only sensor considered - *temporal* fusion, to evolve high accuracy tracks in range and bearing from the low accuracy, bearing-only raw data (some researchers would call this tracking rather than data fusion).

The process at each time step commences with an association stage in which the current set of bearing measurements are allocated to the set of currently tracked entities (or to initiate a new tracked entity), and continues with a Kalman filter or similar algorithm for state estimation in the presence of noise. If multisensor data are available from the IDAS, the processes are identical. The fusion process will be able to converge its estimate of target range, provided there are changes in the line of sight.

In order to simplify this integration task, a radar warner should perform fusion (association) of detected emitter modes into reports of *weapon systems* before offering such reports to the IDAS / Avionics data fusion service.

Range convergence would be assisted by supporting information e.g. from off-platform data (triangulation), or from mission data regarding known threat locations, if integration of such data sources can be achieved.

Recent experiments at DERA UK, using a Kalman-filter based fusion engine, have demonstrated range convergence from simulated radar warner/ESM data [1].

Fusion at level 1 secondly tackles the fusion of identity declarations. This is in many ways more complex than the fusion of kinematic data. There exist a variety of rule-based and probabilistic approaches. STANAG 4162 offers a standardised approach based upon Baysian evidential reasoning. The implementation is difficult, however, identity fusion to STANAG 4162 has been demonstrated by DERA and others, and is being implemented within NATO.

Many platforms carry a range of other sensors, such as radar, infra-red search-and-track, and visual and IR targeting sensors. Such sensors also deliver track and identity data, which should be fused as above, preferably within a single central data fusion service handling all sensing sources.

Once information from all sources on board have been fused to form tracked entity data, tracks from off-board sources and mission data on known threat locations can be fused in, provided that the integration exercise has made such data available.

Fusion at levels 2 and 3 must form threat groupings and priorities. Algorithms at these levels are typically rule or knowledge based.

The end product of data fusion at levels 1 to 3 is a machine held situation awareness, which in a well integrated system, should exist to drive a resource manager, responsible for plan formation and scheduling of various level 4 response packages. Such packages might include:

a) Selection and filtering of information for display to the pilot, to provide (cognitive) situational awareness, and to present decision options, whilst managing his or her workload;

b) Mission re-planning, re-routing to avoid threats whilst fulfilling the mission requirements;

c) Recommendations for tactical manoeuvre;

d) Allocation, timing, and control of IDAS countermeasures;

e) Targeting, allocation, firing and control of any weapon systems which might be carried;

f) Moding and tasking of IDAS and other sensor assets;

g) Reporting back of the situation to higher levels of command, and to other interested allied assets.

4.2 Data Fusion Implementation

There are three principal difficulties in data fusion implementation:

a) data fusion incest, avoided by appropriate architectures;

b) the lack of performance metrics leading to difficulties in validation and acceptance;

c) contractual barriers to satisfactory implementation.

Incestuous fusion of data is the phenomenon in which misleading or low confidence data re-enforces incorrect conclusions, and may be thought of as a form of positive feedback. False alarms may be built into tracked entities, or genuine entities lost. It can occur in networks of fusion processes, within a single platform or across multiple platforms, when true sensor data is not segregated from fused data. When the origin of the data is lost, mis-associations, tracks based upon false alarms, and measurement biases can then be passed around the network reinforcing themselves.

Data fusion incest can be avoided by strict separation of data within fusion processes. Within a single platform, a fusion engine or number of engines should associate and fuse data from the platform's own sensors to form a local track file of entities described in terms of position, heading, velocity and identity. This local track file can then be associated and fused with externally reported tracks and with tracks derived from the mission database, to form a global track file.

Off-platform track information received through some communications medium falls into one of two categories:

a) That originating from commanded units, for example from the fighters within a squadron. Such reports will comprise local track or spoke data. Each platform may only report its local track file, and in it turn it may accept local track file reports from nearby co-operating platforms;

b) That originating from commanding units, comprising an overall air picture, in some form. If the commanding unit has based its track upon reports received from a commanded unit, then that platform, when receiving the track, must be informed that it was one of the contributors.

Figure 1 illustrates the concept, in which incestuous fusion may be avoided.

Data fusion development has been characterised by a lack of satisfactory metrics for quantification of the performance of any product. The pragmatic approach to the testing and validation of data fusion engines has been to assess performance against test data sets in which the "true" picture is known. Research work is underway to develop scientifically based metrics against which products could be validated and accepted.

Some of the greatest potential difficulties and cost drivers in the implementation of data fusion, may arise from commercial barriers between equipment subcontractors and the aircraft avionics prime contractor. It is important in a retrofit or upgrade programme, to establish the commercial links and agreements which mirror the technical interlinkages required to realise the desired level of integration.

5. GROUND SUPPORT SYSTEMS

Any equipment retrofit or upgrade programme must address the issues of spares and servicing: Integrated Logistics Support. However, as these are not unique to DAS and EC, they will not be pursued in this paper. This section will address two aspects of ground support concerning the preparation of the mission - specific data needed for the effective use of EC in the air.

5.1 Pre-Flight Message (PFM) Generation

An essential component of an EC retrofit programme is the provision of a comprehensive facility for producing all forms of pre-flight message required by the integrated DAS. Any growth or upgrades to an in service DAS must be matched by upgrades to any existing pre-flight message generator.

Any additional hardware involved in the transfer of PFMs from the ground facility to the aircraft must also be provided.

The content of the PFM for an IDAS will go beyond the traditional libraries of threat data loaded into the component subunits of the IDAS. It must be able to assign countermeasure responses to threats, including mixed mode and multiple responses. Further PFM information will be required if the DAS is to make use of threat information coming from non-DAS sensors on board, or from any mission library of known threats and their locations.

The PFM will be required to assist in the data fusion process, in particular with the threat prioritisation stage, and with the setting of rules in any rule-based approach to the control and scheduling of IDAS responses.

Post - mission replay and analysis of logged IDAS data could be built into a PFM generation toolset, as could the generation of training scenarios.

The discussion above strongly favours an IDAS architecture requiring a single PFM, over an architecture requiring each element to be supplied with a separate PFM. Similarly a single unified toolset for generating such a PFM is highly desirable. The user will also require test equipment, such as a synthetic environment or reference set of DAS units, in order to test and verify any PFM produced.

Integration of the both the PFM and toolset generating the PFM, with the aircraft mission data and the tools that prepare it (see 5.2 below), is also desirable.

5.2 Mission Planning

An air mission is a sequence of tasks and activities needed of an aircraft, to fulfil some specific objective. Mission planning is the process of generating an acceptable sequence of tasks, given a set of constraints. The constraints typically involve the fuel and weapons load carrying capability of the aircraft, aircraft performance, the availability and disposition of air refuelling assets, civilian air traffic control, de-confliction with both civil and military air traffic, the types of terrain to be overflown and the allegiance of such terrain (i.e. friendly, neutral or hostile), the type and intensity of conflict, the level and types of threat expected, and (of great importance) the political situation and the rules of engagement.

The effectiveness of the EC suite in flight could benefit from mission planning in 4 ways:

a) Access to map referenced locations of known threats, to correlate with sensed data. Also the knowledge of friendly, neutral and hostile areas, and of civil airlanes, could assist in the identification of sensed entities.

b) The type of terrain and of likely civil emissions in any detected band, could influence false alarm rejection algorithms in EC sensors.

c) The more advanced IDAS implementations will offer a choice of self protection strategies. The "best" option might depend upon the phase of the mission, also the type of conflict and the area being overflown. Knowledge of the phase of mission could also be used to select the rules governing the display of information to the pilot, and rules determining how much of the expendables load should be used when. The pilot should remain as the final decision maker; such rules should only influence what is presented as the preferred option.

d) The moding and tasking of EC assets, particularly if shared with other avionic functions. The mission plan should generate at least a baseline rule set, allowing for variation in flight.

The generation of the mission plan should build in any new or upgraded EC capabilities. The ability to challenge some types of threat, and the remaining vulnerability to others should influence the choice of route and flight altitude.

The retrofit / integration programme should also consider:

a) The integration and standardisation of mission planning hardware and software aids (for example to bring pre-flight message generation within the scope of mission planning).
b) The standardisation of formats for data to be downloaded.
c) The integration and standardisation of the hardware involved in transferring any electronic mission plan to the aircraft.
d) The integration of software and mission data load points on the aircraft.

Mission planning will have to (attempt to) manage the pilot's workload and his or her ability to absorb information and take decisions. The more capabilities that EC (and all other) systems offer, the more important this becomes.

6. CONCLUSIONS

The perception of the threat to air platforms, both in intense conflict and in peace - keeping scenarios, has increased in recent years. This perception has prompted, and is likely to continue to prompt, retrofit and upgrade programmes, in the UK and elsewhere, involving defensive aids and other electronic combat equipments.

A key cost driver in such retrofit and upgrade programmes, is the positioning of apertures, and the consequent issue of predicting and verifying the installed performance of the kit.

Another major cost driver is the level of integration of the defensive aids system (DAS) with the platform and its avionics, and the integration features implemented.

Levels of integration range from: (i) the basic mechanical fitting of separate subsystems, each complete with its own set of displays and controls; through (ii) the integration of a defensive aids system within itself, including some common means of display and control; (iii) the integration of the system into existing cockpit displays and controls alongside integration with other avionic systems such as communications, weapons and weapon aiming, and to terrain databases; to (iv) the ultimate level of integration in which the defensive aids become an intimate part of the flight avionics suite.

The features of integration, which can drive programme costs, include:

(i) The fusion of threat and target information from all sensor sources (DAS and other);
(ii) Integrated presentation of information on display devices;
(iii) The use of DAS - sensed data to align sights, sensors or weapons;
(iv) Integration of DAS sensed data and DAS effector status with the communications infrastructure, plus the ability to make use of off-board data;
(v) The integration of DAS with mission level control and decision making functions; and
(vi) The integrated control of multi-functional or shared aperture devices.

Other on-board integration issues involve the logging of DAS and other mission data, and the integration of on-board training facilities.

The total retrofit or upgrade programme must also address ground support issues such as the generation of pre-flight messages, and the means of mission planning.

The level of integration, and the integration features implemented, impact not only upon the cost and complexity of the equipment retrofit, and the cost and complexity of new and upgraded ground support facilities, but also upon the cost of re-certification of the entire aircraft as modified.

The desired level of EC integration, emerging from a retrofit or upgrade programme, will be driven by the customer's specification, which in turn is scoped by his understanding of the detailed issues in integration: the features and facilities which are both feasible and operationally useful. It is necessary to maintain a research infrastructure, and scientific expertise, to support the military customer in this understanding.

A risk exists that, in programme implementation, integration features may be sacrificed to contain costs, resulting in fits of expensive and capable items of kit which cannot be used operationally to their full potential.

7. ACKNOWLEDGEMENTS

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8. STATEMENT OF RESPONSIBILITY

Any views expressed in this paper are those of the author and do not necessarily represent those of the UK DERA, nor of H.M. Government of the United Kingdom.

GLOSSARY

ASIC	Application Specific Integrated Circuit
DAS	Defensive Aids System
DERA	Defence Evaluation and Research Agency
EC	Electronic Combat
EM	Electro-Magnetic
EO	Electro Optic
ESM	Electronic Surveillance (or Support) Measures
HMI	Human Machine Interface
IDAS	Integrated Defensive Aids System
IMA	Integrated Modular Avionics
IR	Infra Red
JDL	Joint Directors of Laboratories
LWR	Laser Warning Receiver
MANPADS	Man Portable Air Defence Systems
OODR	Observe, Orient, Decide, React
PFM	Pre-Flight Message
RF	Radio Frequency
TV	Television

REFERENCES

1. Zanker, P.M., Chillery J.A. and Ferry, M.D.; "Data Fusion in support of Electronic Combat", Oct. 1998, 3rd NATO/IRIS Joint Symposium, Québec, Canada

JDL-97 Level	Function	OODR level
Level 0	Pre-processing, formatting, alignment of co-ordinate frames, pixel-level processing	-
Level 1 (Object refinement)	Association (of plots or tracks) with each other and with currently recognised tracks, or to commence a new track	Observe
	Fusion of plots or tracks to form entities tracked in position and heading. Optimal use of new measurement data to update track parameters.	
	Prediction (project tracks into the future)	
	Classify entities, de-clutter	
	Identify entities (fusion of separate declarations of identity, build up of identity evidence)	
Level 2 (Situation assessment	Formation of the air / surface picture (entities fused into groups, with assessment of intention)	Orient
Level 3 (Impact assessment)	Threat prioritisation	
Level 4 (Process refinement)	Plan formulation, scheduling	Decide
	Reaction packages (command DAS effectors, mode and task sensors, display to pilot, communicate off-board, mission re-planning, weapon allocation etc.)	React

Table 1 Data Fusion Functions against the JDL and OODR Models

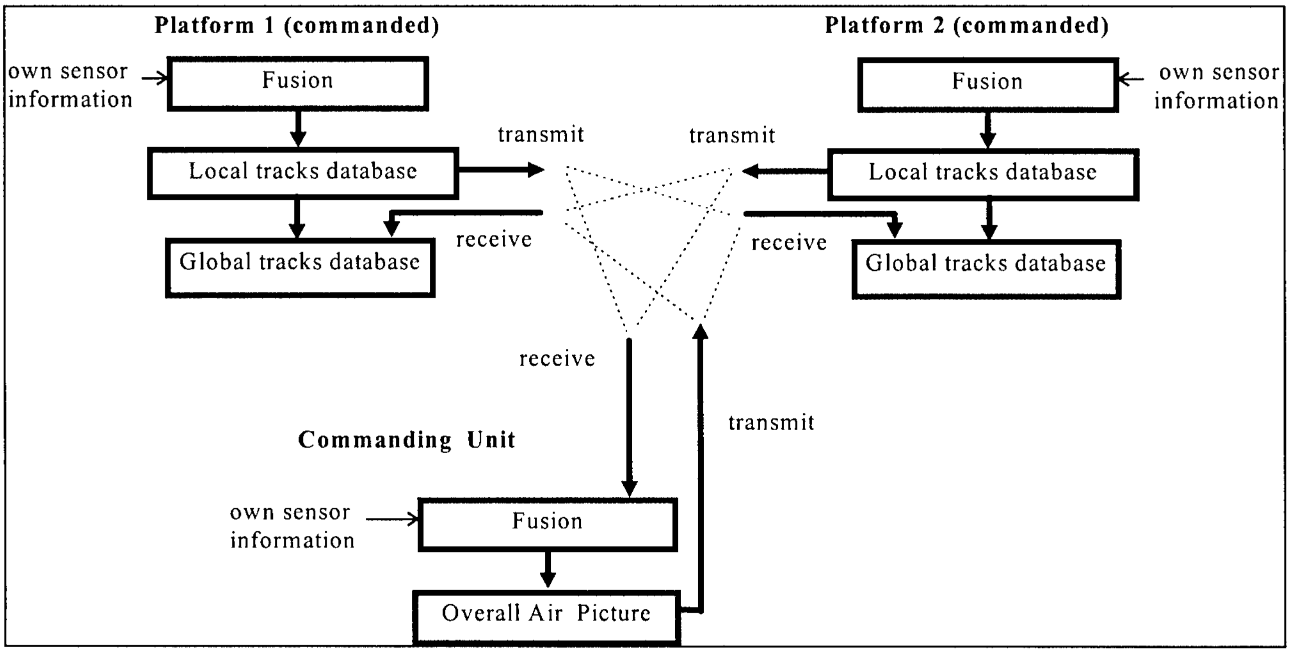

Figure 1 Data Fusion Structure Avoiding Incestuous Fusion