Group Operations: Synergy Through the Exploitation of Technology and Tactics

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SUMMARY

This paper examines Group Operations (i.e. missions and composite air operations containing more than one aircraft of similar or different types). In particular, it considers current practice, looks at key issues for consideration, and identifies future potential from operational, technical, and cost effective viewpoints.

From these operational requirements, functional requirements are derived and grouped into three broad areas: improved situation awareness; improved reactive capability; and improved co-ordination.

Technologies and 'Total System' implementation concepts to meet such requirements are then identified. The paper concludes with a summary of the key technologies, their benefits and associated risks. Furthermore, the possibility is proposed for an evolutionary route to achieving an enhanced Group Operations capability with near, medium, and long-term options. However this can only be achieved through detailed Technology Feasibility studies and Tactics development.

1. INTRODUCTION

In today's post Cold War era, the RAF is faced with a number of capable, smaller, more diverse threats. In recognition of this, NATO's New Strategic Concept [Ref 1] calls for a capability to counter a major threat and intervene in smaller crises or undertake peace support operations around or outside NATO's borders. These facts, when combined with shrinking defence budgets, pose a formidable challenge for the RAF. In short, it must 'do more with less'. A point echoed by Gp Capt. Woolley from the Air Warfare Centre [Ref.2]:

> *"The RAF's former role in NATO's Central Region has left us with many strengths, including a qualitative operational 'edge' over most potential adversaries. However, now that we can more clearly see the emerging trends of future operations, perhaps the time has come for a reappraisal of how we should organise, equip, and train".*

Of course the changing world scene in political, industrial and technological terms presents similar challenges for the defence industry. It is the way that the RAF and the defence industry meet these challenges that will determine their future success. In particular for group or COMposite Air Operations (COMAO), this can be achieved through the exploitation of new and emerging technologies and appropriate tactics. For example, technologies such as covert communications and distributed data fusion can enable increased synergy and co-operation between a group of aircraft.

This paper examines existing operational implementations and future concepts for both air-to-air and air-to-ground group operations. Furthermore, it identifies and recommends future additions and/or modifications to avionics systems to realise such concepts.

1.1 Terminology

The term 'Group Operations' per se is ambiguous. To some it is seen as close co-ordination between aircraft in a small formation (e.g. a four-ship); to others it represents co-ordination (usually pre-planned, pre-mission) across a large raid package. In short, individuals have different perceptions of Group Operations.

The term 'Group' may be applied at different levels to the following:

- A collection of like aircraft with the same objective;
- A collection of like aircraft with a composite objective;
- A collection of like aircraft with physically or temporally disparate objectives;
- A collection of unlike aircraft in the same role;
- A collection of unlike aircraft co-operating in unlike roles;
- A joint and/or combined force involving air/land/sea assets.

The RAF however uses more precise terminology to describe 'Group Operations', as the following (paraphrased) examples illustrate:

Sortie: A single aircraft performing a task in pursuit of an objective.

Mission: More than one aircraft (usually of the same type) pursuing the same objective.

Composite Air Operations: More than one aircraft (of similar or different types) pursuing the same overall objective, possibly with different individual sub-objectives. For example, a bomber raid escorted by fighters. Alternatively, a mixed package of fighters (e.g. Tornado F3s with F-15Cs) on a Fighter Sweep mission.

We adopted this terminology for reasons of clarity and consistency. Furthermore, to maintain sight of the aims and objectives, a suitable working definition or vision of a future 'group operations' capability has been derived:

> ***"An enhanced capability to perform missions and composite air operations through the exploitation of current and future technology with appropriate use of tactics."***

Paper presented at the RTO HFM Symposium on "Collaborative Crew Performance in Complex Operational Systems", held in Edinburgh, United Kingdom, 20-22 April 1998, and published in RTO MP-4.

2. CONTEXT

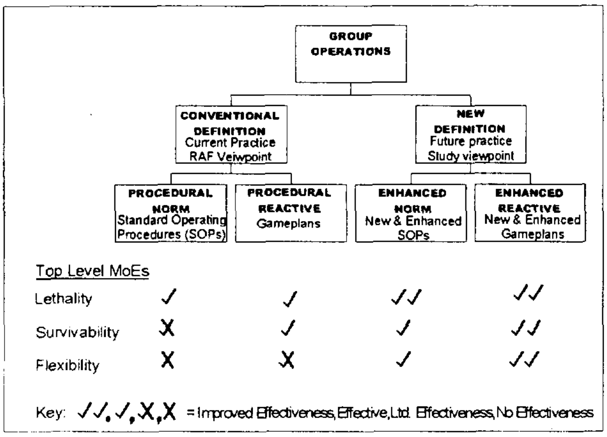

Figure 1: Group Operations in Context

Figure 1 places the RAF and our viewpoints of 'Group Operations' in context. The conventional definition relates to current RAF practice. Here, current/in-Service technology is used with operational and tactical doctrine, techniques, procedures (both normal & emergency) and training to deliver a 'Group Operations' capability. The new definition relates to possible future RAF practice. Where both current and future technology are used in conjunction with new and appropriate doctrine, procedures and training to deliver an 'Enhanced Group Operations' capability.

Note, the measures of effectiveness (MoEs) shown in the diagram broadly illustrate where potential improvements could be made and to what extent.

Current RAF practice makes best use of available technology and resources and can be characterised as:

Procedural/Prescriptive

The conduct of missions and composite air operations is largely governed by techniques and procedures in the form of Operational Orders and Standard Operating Procedures (SOPs). These exist at various levels - Squadron, Wing, or Force (e.g. Harrier Force) - in order to provide (at the appropriate level):

- Standardisation (to reduce ambiguity);
- Inter-operability (to improve availability/effectiveness);
- Conciseness (to reduce complexity).

Limited Communication

In medium and high intensity conflicts, communication between both airborne assets and with C^3I assets is strictly limited by emission control procedures for reasons of surprise and security. Where radio silence is broken, as in the case of an emergency or unexpected engagement, voice messages are normally conveyed in short bursts using standard codewords.

In low intensity conflicts and operations other than war such restrictions may be relaxed, but this is largely scenario dependent. Furthermore, there is a strong emphasis on Rules of Engagement in such operations and tight political control is often the norm. Consequently, such operations are typically characterised by significant amounts of communication, cross-checking, and co-ordination; a situation that is often exacerbated when placed in a multi-national context.

Limited pro-active/reactive capability

Responses to changed circumstances, particularly unexpected engagements by enemy fighters or SAMs, is largely reliant upon pre-briefed gameplans. These can be generic or specific to a 'known' threat type and provide a coherent and standard set of reactions. However, they are by no means comprehensive. This practice, when combined with limited communication, effectively limits the RAF's ability to exploit some of the key 'Principles of War' [Ref 3] during missions and composite air operations, namely:

- Rapid concentration (and dispersion) of Force at the decisive time and place;
- Economy of effort (i.e. balanced/optimum use of resources);
- Flexibility;
- Co-operation.

Prior to and during the Gulf War (c.1991), air power in general may have operated within a somewhat rigid structure. For example, if a raid package required support assets (e.g. SEAD aircraft) both elements would be time co-ordinated but otherwise independent. It is now perceived that there is scope for improving such a situation. Through increased co-ordination between airborne assets and associated C^3I.

2.1 Current Composite Air Operations

Based on discussions with the Tactical Doctrine and Training element of the RAF's Air Warfare Centre, this section describes a typical current day COMAO as shown diagramatically in figure 2, appendix B.

The target is assumed to be a large airfield located approximately 100 km beyond the Forward Line of Own Troops (FLOT). The COMAO package is composed of the following elements:

Fighter Sweep

A number of fighters flying ahead of the main raid package, typically at medium altitude, with their radars active and tasked with clearing a pre-defined corridor of airborne threats.

Main raid package

A main raid package of variable composition which is dependent upon the mission objective and perceived threat.

It may contain the following:

- Embedded fighters (i.e. within or to the side of the package performing an escort function);
- Embedded Suppression of Enemy Air Defences (SEAD) aircraft (usually at the front of the package);
- Interdiction aircraft.

Note, the mission commander will usually be part of the main raid package and may delegate 'kick authority' (i.e. re-routing control) to other elements within the COMAO e.g. SEAD aircraft.

Supporting Elements

Several supporting elements operating outside the main raid package typically engaged in:

- Reconnaissance:

  Pre-raid: Up-to-date targeting information is passed to the main raid package via a Reconnaissance Attack Interface (RAI).

  Post-raid: Facilitates a Battle Damage Assessment.
- SEAD;
- Tankers;
- AWACS.

Flexibility of current Composite Air Operations

Since the size of a COMAO may be anything up to 50 aircraft there is only limited flexibility to respond to changed or unforeseen circumstances. Where appropriate, minor changes to the route or Time-On-Target (TOT) can be made. However, these pose significant situation awareness and co-ordination problems amongst the different elements of the COMAO. For example, if the main raid package calls a late TOT, the preceding SEAD and Fighter Sweep must be notified to ensure adequate protection is available over the target area at the now later time. If not the mission must be aborted. Ultimately, it is the mission commander who must exercise judgement, balancing overall success against the risk of conflicting with other concurrent missions in the area.

2.2 Future World Trends

At a time of significant political, industrial and technological change it is perhaps opportune to consider how current RAF practice may evolve. This section identifies several key issues that must be addressed if the RAF is to meet the requirements of a changing world scene.

Out of Area Operations

Increasingly the RAF is being involved in Out of Area (OOA) operations, often to undertake Peace Support Operations (PSO). These are typically Joint (Multi-Service) and Combined (Multi-National) operations and may be undertaken by NATO, WEU, or UN forces. Such crisis or conflict resolution activity may involve a variety of operations ranging from disaster relief, peacekeeping and peacemaking, to peace enforcement.

Problems associated with multi-national peace support operations are not to be underestimated. There are a number of difficult areas, particularly when non-NATO nations are involved, namely: Command and Control (C^2); Rules of Engagement; Communications inter-operability.

Changing nature of the threat

As Gp Capt. Woolley [Ref 2] points out:

> *"Peace Support Operations (PSOs) will increasingly influence how we (the RAF) operate, organise, equip and train."*

Nevertheless, the changing nature of the more sophisticated threats means that War operations will also be affected. Such threats now have advanced technologies such as stealth, low frequency radars, and directed energy weapons, all of which pose a formidable problem.

New & emerging technologies

To counter such threats, it will be necessary to exploit new and emerging technologies and develop new and appropriate tactics. For example, warning and responses to threats can be improved through sensor management across a group of aircraft, covert communication, data fusion, and advanced cockpit-vehicle interfaces (CVI). US projects such as TALON SWORD and TALON LANCE which aim to achieve enhanced situational awareness by augmenting aircraft sensors with information from space-based assets and other aircraft.

Future combat aircraft

Future combat aircraft must be designed to meet the exacting requirements of both peace support and wartime operations. Furthermore, such designs must exploit both current and emerging technologies to ensure efficient and effective missions and COMAO. Inter-operability is likely to be a major concern for such an aircraft, on two counts:

- Multi-national operations may require 'backwards' compatible systems to enable future combat aircraft to operate with less sophisticated , non-NATO standard aircraft;
- Different aircraft build-standards (across a force of aircraft of the same type) may lead to sub-optimum effectiveness.

2.3 Mission Analysis

Whilst the key issues described above are important, their broad nature precludes a detailed investigation of future COMAO. Consequently, we chose here to examine future COMAO in the context of the Future Offensive Air System (FOAS). This weapon system is likely to be multi-role: primarily air-to-surface with a credible, albeit secondary, air-to-air role. The final solution has yet to be defined but is likely to be an optimum mix of manned and unmanned combat air vehicles and stand-off weapons. As such FOAS serves as a useful baseline from which to examine COMAO.

Key design design drivers for FOAS are:

- Affordability;
- Lethality;
- Flexibility;
- Availability;
- Survivability.

Within this context, we considered:

- Strategic Operations;
- Offensive Counter Air (OCA) Operations:

  SEAD;
  Fighter Sweep (FS);
  Escort;
  Airfield Attack.
- Air Support of Land Operations:

  Air Interdiction (AI);
  Offensive Air Support (Battlefield Air Interdiction (BAI));
  Tactical Air Reconnaissance (TAR).
- Maritime Air Operations:

  Anti-surface Warfare (ASUW).

Operational analysis of these missions was focussed on two critical phases within each mission: Target Attack and Threat Penetration(i.e. both Surface-to-Air and Air-toAir). Each mission was analysed and key operational issues relating to COMAO identified. For example:

2.3.1 Target Attack

Air Interdiction (Man-in-the-loop)

Target type:	Fixed hard targets Single point e.g. Bridge.
Weapon type:	Man-in-the-Loop Guided Bomb e.g. Paveway III, AGM-130.
Key issues:	Highly organized weapon aiming: coordinated acquisition & targeting; Possible third party targeting.

Fighter Sweep

Target type:	Highly mobile & threatening e.g. enemy fighters.
Weapon type:	Autonomous Medium & Short Range Missiles, Gun, DEW.
Key issues:	Coordinated target acquisition; Weapon-to-target allocation; Need for high situation awareness & mutual support; Need to maintain cohesion.

2.3.2 Threat Penetration

Threat Avoidance

Threat type:	Enemy SAMs and/or Fighters
Key issues:	Acquisition of threats; Mission profile (vs. SAM); Group tactics: highly defensive, no weapons just countermeasures; Need for high situation awareness & mutual support; Need to maintain cohesion.

3. FUNCTIONAL REQUIREMENTS FOR GROUP OPERATIONS

For future COMAO, technology alone will not deliver an enhanced capability. Sound and coherent tactical doctrine must be in place. Furthermore, for full exploitation, appropriate training policies and sound teamwork principles must be followed to ensure aircrew competence and confidence in the use of new technology. So enhanced in-service capability can only be achieved through a combination of: technology; appropriate tactics and effective training.

From our analysis (which employed teamwork [Ref 5] and systems theory [Ref 8]), the following key improvements in functionality were identified:

- Situation awareness;
- Reactive capability;
- Co-ordination.

3.1 Improved Situation Awareness

Situation awareness is a term used to describe the view perceived by a person or object of itself, the outside world or external environment, and the relationship between them. In essence, it is the first two phases of Boyd's Observation, Orientation, Decision and Action (OODA) cycle, details of which are provided in appendix A. Nevertheless, we considered that the term 'Situation Awareness' could be decomposed into three specific categories:

- High Situation Awareness;
- Common Situation Awareness;
- Role Situation Awareness.

High Situation Awareness

High situation awareness relates to the conventional views of maximum sensor coverage, high accuracy, and fast update rates. The aim here is to shorten and improve the quality of the COMAO's Intelligence gathering (i.e. Observation and Orientation) phase. This facilitates quick and effective action and helps to generate a superior tempo of operation relative to a threat or target.

With the advent of JTIDS, this form of situation awareness will undoubtedly improve. However, even JTIDS has its limitations: in particular, data latency (typically 12 seconds) and unnecessary multiple reports (from different observers) of the same contact. This leads to stale and multiple contacts, all of which must be resolved to enable an accurate situation assessment.

For future COMAO, therefore, the following functional improvements to high situation awareness are required:

- Optimisation of the COMAO's sensor coverage, update rate, and accuracy;

Sector allocation to individual COMAO package members, for example, could enable the effective 'dwell time' in any one sector to be increased, resulting in improved detection and tracking performance.

Alternatively, all but one of the COMAO package members could use passive sensors for threat/target detection. The 'active' member would use low probability of intercept (LPI) radar techniques to covertly gather accurate threat/target range data which would then be disseminated to the rest of the COMAO.

- Time tagging of sensor reports.

  By time tagging sensor reports (i.e. target/threat detections) as and when they occur, and distributing such information throughout the COMAO, problems associated with data latency and multiple contacts can in many instances be resolved.

Of course, whilst all members of a COMAO may possess high situation awareness, they may not necessarily have a common 'big picture'. This is the second category of situation awareness.

Common Situation Awareness

Common situation awareness relates to the view that 'man is the limiting factor' to situation awareness. In short, technology provides the data, and then transforms and presents it as information. Each member of the COMAO will then draw conclusions from this based upon their individual perception of the situation. Such perceptions are often incongruent and biased towards a member's own objectives and circumstances. In many instances, this can lead to reduce synergy and cohesion amongst the COMAO.
There is a requirement, therefore, for each member of the COMAO to have common data about the organisation and objectives of the COMAO, and the environment in which the package is operating. This data will be transformed and presented as information, so that each member may form a common perception of the total group situation, as well as the situation applicable to his own objectives and circumstances.

In summary, common situation awareness is gained through common perception; see figure 3.

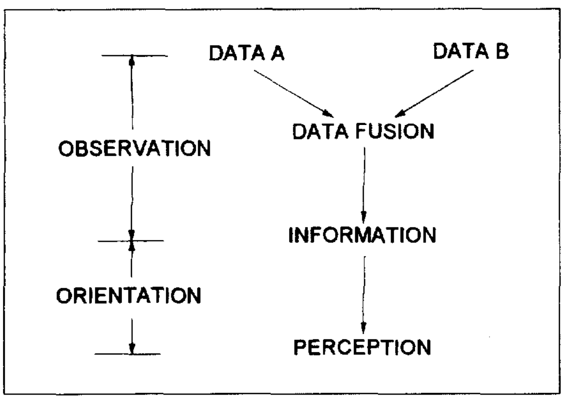

Figure 3: The Elements of Common Situation Awareness

Role Situation Awareness

This third category is closely related to common situation awareness. In short, to minimise confusion and ensure efficient use of assets all members of the COMAO must be aware of each other's roles and responsibilities. This is especially important when circumstances and/or roles change during a mission e.g. change of leader due to attrition. Furthermore, from the common data and information presented to the COMAO, each individual aircraft must have the ability to select and display information to the crew that is appropriate to its specific role and assigned task.

3.2 Improved reactive Capability

Reactive capability, that is the ability to respond to changed circumstances, is closely linked to situation awareness and relates directly to flexibility. In essence, it is the decision and action phases of Boyd's OODA cycle. The key to an improved reactive capability for future COMAO is, assuming adequate situation awareness:

- Accurate and timely situation assessment;
- Better informed decision making;
- More effective action.

Situation assessment and decision making

Whilst pre-briefed gameplans and Standard Operating Procedures (SOPs) are likely to remain an effective and coherent way of dealing with changed circumstances, they are by no means comprehensive. Against an unexpected SAM threat, for example, the mission commander must perform an accurate and timely situation assessment and decide the most appropriate course of action. This may involve re-routing the whole COMAO package around the threat (whilst remaining within a designated corridor) or aborting the mission entirely. In either case, a significant number of factors and the impact of particular courses of action need to be considered in a short space of time:

- Threat (numbers, type, capability);
- Re-route options;
- Fuel, time and profile implications;

Future COMAO will therefore require both situation assessment and electronic decision support systems to ensure both a high tempo of operation and an appropriate response to such circumstances. These studies have focused on improving the effectiveness of the aircrew/single aircraft combination through intelligent data processing, planning, and implementation functions to assist the aircrew. To extend electronic support tools to support multiple aircraft operations, we believe that a number of additional requirements should be taken into account. Including:

- hierarchy of command;
- synchronisation with external supporttools;
- different cooperative roles of group members;
- synergy.

The efficacy of such requirements in relation to future COMAO, however, remains to be proved. Inter-operability is likely to be a major issue in multi-national operations, especially with non-NATO forces. Different nations will undoubtedly possess different aircraft types, levels of technology and procedures. Aircraft equipped with electronic support systems may be able to compensate for this, but there will always be an overarching requirement for greater co-ordination and communication in such situations.

Effective action

Current procedures and technology limit the number of effective actions a COMAO can undertake in response to unplanned events. In short, structure (i.e. procedures, technology, organization and training) produces behaviour, and changing theses underlying structures can produce different patterns of behaviour.

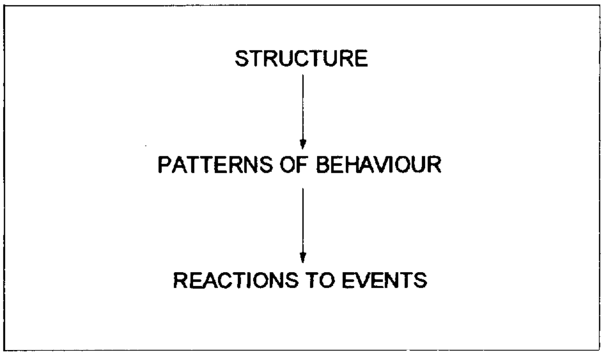

Figure 4: Reactions to Events - The Fundamental Explanation

By changing such structures more effective action can be realised, for example:

- In-flight Re-targeting:

  Should the main raid package suffer some attrition the highest priority Desired Mean Point of Impact (DMPI) for the raid can be re-assigned to the most appropriate aircraft;

- In-flight Re-roling:

  In completing one task, some aircraft may be able to re-role whilst airborne. F-15Es in Bosnia, for example, regularly undertook air defence missions (i.e. combat air patrols) following their ground attack mission, once they had refuelled from a tanker;

- Holistic and cohesive defence:

  An omni-directional 'defensive shield' against a variety of threats can be realised through a combination of new technology, tactics and training.

3.3 Improved Co-ordination

COMAO by definition requires co-ordination. However, this is merely a means to greater synergy within a group i.e. achieving an optimum combined effort. To exploit 'The Principles of War' and improve effectiveness future COMAO will require increases in both synergy and cohesion. A brief discussion follows:

Synergy

A group of co-operating elements is said to exhibit synergy when the capability of the group as a whole is greater than the sum of the capabilities of the individual elements. Synergy results from both diversity between elements (i.e. different roles, skills and attributes) and effective co-operation between those same elements (i.e. teamwork). Over the last fifteen years, extensive research has been undertaken into synergy and effective teamwork [Ref 5]. This research has identified a number of key characteristics which are required to formulate a 'team', including:

- Definable membership: the members must be identifiable, by name or type;
- Group consciousness: the members must think of themselves as a group;
- Sense of shared purpose: the members must have a common objective;
- Interdependence: the members need help from each other to achieve the common objective;
- Interaction: the members communicate with each other, influence each other, and react to one another;
- Unitary system: the members work together as a single entity.

In summary, we have concluded that synergy can be increased by improving the way aircraft work together as a team. This can be realised through:

- Technology to support cohesion and procedural responses;
- Development of appropriate tactics concurrently with technology, in order to fully exploit the technologies and guide their development. This will require:

  Operator involvement upfront in product development (i.e. Feasibility onwards);

  Multiple man-in-the-loop simulation;

  Operational Analysis combat modelling to test the robustness of new tactics;

- Development and introduction of appropriate training schedules.

Cohesion

Cohesion is 'the act of sticking together'. Fundamental to this concept is the need for effective communication and common situation awareness. Without both of these cohesion is likely to be low or very tenuous. Even with these two fundamentals present, cohesion may still be temporarily broken by:

- one or more members leaving the COMAO for some reason e.g. low fuel state;
- a new member joining the COMAO e.g. rendezvous with tanker or fighter escort;
- the group temporarily splitting and rejoining later .

For future COMAO, therefore, there is a requirement to generate and maintain cohesion (throughout a mission) by means of the following:

Effective communication

All elements of the COMAO must be able to communicate with each other as and when required, and where appropriate with higher command authorities and external agencies. Whilst such communications will need to be clear and concise to be effective, they must be neither detectable nor decipherable by enemy forces or other (unauthorised) third parties.

In addition to secure voice, data links will be required to convey information between different elements of the COMAO and with external agencies. They will be required to cover a wide range of operation (e.g. from 10km to beyond 80km) and a variety of bandwidths and data rates (e.g. from a few kilo bits per second to beyond one megabits per second).

Common Situation awareness

Each element of the COMAO must possess a common 'big picture' of the total situation, as well as the situation applicable to his own objective and circumstances.

Benefits of greater synergy and cohesion

Once these fundamentals are in place, the COMAO package can operate as a cohesive team, and can create and exploit synergy in novel ways. Group asset management, for example, allows the total assets (e.g. sensors, weapons, countermeasures) of the COMAO to be utilised in an optimum manner for the benefit of the group as a whole.

Group sensor management and data fusion, for example, could provide the following benefits:

- Omni-directional sensing of threats;
- Co-ordinated acquisition and targeting through optimum sensor coverage, update rates, and accuracy;
- Early resolution of multiple contacts and 'ghosts';
- Covert sensing strategies (e.g. bi-static radar, or LPI radar plus several IRSTs);
- Multiple redundant sensing.

Group weapons management could provide:

- Optimum allocation of firepower - vital in air combat to reduce inefficient over-allocation of weapons;
- In-flight weapon to target re-allocation i.e. the ability to upgrade the desired mean point of impact (DMPI) to a higher priority ground target;
- Guided weapons hand-off to other members within the package.

Group countermeasures management could provide:

- An omni-directional 'defensive shield' against a variety of threats;
- Co-ordinated threat deception e.g. blink jamming;
- Optimum use of countermeasures e.g. more efficient use of expendables.

In summary, by taking account of the location, capability and status of individual elements of the COMAO, and providing a holistic and co-ordinated response, group asset management will bring greater synergy and effectiveness to future COMAO.

4 SYSTEM CHARACTERISTICS

To realise the required operational effectiveness improvements for future group operations (as summarised in figure 1), the group of aircraft must be designed to operate as a whole system. Furthermore, in the wider context of a multi-national task force, this 'System' must operate as part of a much bigger 'System of Systems'. As a consequence, like any system, the group of aircraft must possess a number of key system level characteristics including high degrees of robustness, dependability and flexibility. These characteristics are briefly examined below.

Robustness

To be robust in their operation, highly integrated group assets must be insensitive to single element failure. Key contributing elements to the group include platforms, sensors and communications. In each case the system needs to be designed so that partial or full loss of any of these leads to a graceful degradation in performance. At all times the integrated group must perform at least as well as the 'non-integrated' group would have done using current practices and conventions.

Duplication or distribution may provide protection against the loss of key platforms or resources.

To compensate for localised sensor failure, degraded sensors would be screened out by robust data fusion and the desired coverage would be maintained by re-allocation of unaffected sensors by the sensor management function.

A robust communications management system would aim to minimise disruption and ensure optimal recovery when links are re-established.

Sensors and communications should be jam resistant and, where possible, should minimise the probability of provoking ECM systems through covert behaviour.

Dependability

Whereas robustness is concerned with continued, gracefully-degrading, viable operation in unfavourable conditions, dependability is concerned more with high availability for use. If a system is dependable, no likely fault state would be capable of causing total loss of capability.

Dependable designs avoid dependence on the availability of single vulnerable unit or equipment.

Flexibility

Flexibility is essential for a group operations system. The group may come into being shortly before a mission. It may exist for a few missions only and then be broken up and the member platforms become part of other groups within which they must make an equally cohesive but not necessarily identical contribution.

Inter-operability with aircraft of other roles and with allies' aircraft is essential. Within a multinational task force, other group members and force assets such as tankers, surveillance and C^2 might be provided by other nations. Thus, varied levels of integration may exist within the group with links across national boundaries provided by international standard data links.

Other forms of flexibility are required: additions and losses to the group must be accommodated as well as changes in mission.

5 SYSTEM ARCHITECTURES

A fundamental feature of the group operation may be that command is devolved from the base to the group. In such circumstances, command responsibility would lie with a single group commander. However, the computing support required to enable the distribution of tasks and information in a co-ordinated way may lie on one or few platforms or they may be distributed among many or all platforms. These extremes of approach are discussed below and are referred to as the "group leader" and the "fully integrated" architectural models.

5.1 Architectural Models

Group Leader model

Within this model one platform acts as "group leader", and provides all the management and co-ordination processing. Platform data is fused on the platform that gathered it and broadcast across the group. Each aircraft may have knowledge of 'total picture' by fusing data from other platforms with its own data. However this is essential only for the group commander platform since the native data fusion capabilities would be optimised to provide the necessary situation for their role.

Individual platform assets such as sensors and defences would operate autonomously in the absence of instructions from the command platform. However, the command platform would monitor the state of the group and issue corrections when divergence occurred and would issue new tasks as they arose. It would also provide the link to the outside world and would be responsible for the group dealing with its base. A back up platform (perhaps several) would be required to 'shadow' the group commander platform to effect seamless takeover when necessary through attrition or other loss.

The advantage of such an implementation is that only the command platform and its back-ups would require extra capabilities. Other platforms could contribute to such a group without undergoing change.

Fully Integrated model

Within this model, no single platform carries out all the processing required for group functions. All group assets are managed as a 'whole system'. For instance, data fusion and asset management would take place in a distributed processing architecture across the group.

Such a processing architecture would be designed to ensure graceful degradation of the system when capabilities were lost due to attrition or malfunction. Its great advantage is its power to utilise emerging technologies to provide every member platform with up to date, fully optimal information. This in turn would promote greater group effectiveness.

Other options, between these two extremes, exist and need to be examined. In practice, the choice of architecture will depend on a trade-off of communications bandwidth and latency, system robustness, total processing load, development risk etc.

5.2 Whole/Group System technology requirements

Whichever system model is adopted, there are three interdependent fundamental supporting systems level technology requirements:

- Distributed data fusion.;
- Distributed mission processing;
- Covert communications.

Distributed Data Fusion

This technology enables fully optimal data fusion to be distributed across a tactical group so that all member platforms will have full simultaneous access to a common group picture (i.e. common situation awareness). Such a system would be capable of distributing identity processing (i.e. identification of a specific threat type) just as readily as position and motion estimation. In this way track identity conflicts would be avoided automatically because every platform sees the full picture, derived from all the available data.

Distributed Mission Processing

This technology allows mission processing tasks such as sensor and weapon allocation (and possibly even platform tasking in response to pop-up threats) to be distributed among the platforms. Given the same view of the world, participating elements should all reach the same conclusion as to who does what and when. This involves the employment of situation assessment, task generation and planning functions to arrive at a common plan for the group as a whole. Conflicts must be avoided both within the group and, at a higher level, between groups.

The ability to do distributed automatic mission processing depends on the ability to disseminate the group picture among the members of the group, with insignificant latency and divergence of content.

Covert Communications

A reliable communications system will be required to support distributed processing. The system should be secure, covert, high data rate and low latency. Technologies will be required to support short range (line of sight up to a few kilometres), medium range (up to maximum line of sight) and long range (beyond line of sight).

5.3 Component Enabling Technologies

Key 'component' technologies which will be required to support future COMAO include:

- Unambiguous and timely covert communication;
- Distributed sensing (i.e. spatially separated across the COMAO package);
- Group asset management:
- Sensor management across the group;
- Countermeasures management across the group;
- Weapons management across the group;
- Data fusion;
- Data and Information Management;
- An intuitive and high quality CVI;
- Situation assessment support tools;
- Decision support tools;
- In-flight adaptive planning tools.

These technologies and how they satisfy the functional requirements for enhanced group operations are discussed below:

5.3.1 Achieving Situation Awareness/Assessment Requirements

High Situation Awareness

The aim of high situation awareness is to shorten and improve the quality of the COMAO's Intelligence (i.e. Observation and Orientation) gathering. This can be achieved through the following combination of technologies:

- Distributed sensing (i.e. spatially separated across the COMAO package);
- Sensor management across the group:
- Unambiguous and timely covert communication:
- Data fusion;
- An intuitive and high quality CVI.

Common Situation Awareness

To ensure each member of the COMAO has common data and information from which to form a collective perception of the total group situation, the following technologies will be required:

- Unambiguous and timely covert communication;
- Data fusion;
- Data and Information Management:

  Before fused data can form the basis for decision making, it must be organised with respect to the immediate concerns and roles of the decision making system. It must do this in ways which are appropriate not only for the human, but also for other decision support systems.

  Database handling technologies to support data and information management are under development, including associative memory systems.

- An intuitive and high quality CVI:

  In recent times, the volume of information available to modern combat aircraft has 'mushroomed'. Graphical display systems allow information to be presented to the crew as required, selectively and as appropriate to the role and task concerned [Ref 6, 7].

  It is vital that information presentation techniques are developed to optimise crew workload, and ensure common situation perception across the group. Technologies for information management and the manner of its presentation are under development.

5.3.2 Achieving an Improved Reactive Capability

To provide accurate and timely situation assessment, better informed decision making, and more effective action the following technologies will be required:

- Situation assessment support tools;
- Decision support tool;
- In-flight adaptive planning tools.

5.3.3 Achieving Improved Co-ordination

To improve synergy and cohesion within a COMAO the following technologies will be required:

- Unambiguous and timely covert communication;
- Common and high situation awareness (see 5.3.1);
- Group asset management (e.g. bi-static radar, co-ordinated countermeasures - blink jamming).

6 CONCLUSIONS

This paper has examined Group Operations (i.e. missions & composite air operations containing more than one aircraft of similar or different types). In particular, it has considered current practice, key issues and trends, and has identified future potential from both operational and technical viewpoints. From this analysis we have concluded the following:

(i) Functional requirements for future group operations can be grouped into three broad areas: improved situation awareness; improved reactive capability; and improved co-ordination.

(ii) Key system level technologies to meet such requirements include:

- Distributed (i.e. across the group) Data Fusion;
- Distributed Mission Processing to provide:

Group asset management (i.e. sensors, weapons, countermeasures);

Data and information management;

Situation assessment support tools;

Dedicated wide band covert communications;

Intuitive and high quality CVI.

(iii) In exploiting such technology the following benefits to future group operations will be accrued:

- Affordability - through more efficient use of assets and improved survivability;
- Lethality - through improvements in co-ordinated (in-flight) weapons management;
- Flexibility - via group asset management (i.e. sensors, weapons, countermeasures across the group);
- Availability - via multiple redundant systems (across the group) and co-ordination to mitigate system failures and attrition effects;
- Survivability - through co-ordinated sensor and countermeasure management providing a 'defensive shield' against a variety of threats.

(iv) To realise such benefits in FOAS timescales industry and the military will need to jointly pursue the following activities:

Evolve In-Service Capability

Whilst the technologies we have identified are realizable within FOAS timescales, they should not bring about a revolution in capability when they enter service. It is preferable that in-Service capability should evolve with the technology. For example, minor modifications and upgrades to current avionics could provide modest improvements to current COMAO (e.g. the addition of track quality and latency information to target/threat reports distributed via tactical datalinks). Furthermore, an evolutionary route will enable inter-operability concerns (e.g. operations with less sophisticated, non-NATO standard aircraft) to be resolved earlier during the design phase rather than later when FOAS is in service.

Concurrent and evolutionary tactics & technology development

Tactics need to be developed concurrently with the key technologies to fully exploit the technologies and guide their development. As such Service doctrine and operational evaluation units should be involved upfront in product development (i.e. Feasibility onwards) and evaluation. This goes beyond the traditional 'cockpit layout' involvement of aircrew and seeks to develop new and different techniques for using the technology. Such development activities will require a broad range of methods and tools including operational analysis combat modeling; real time multiple human-in-the-loop simulations; and weapon system concept design tools.

Technology Feasibility/Development Studies

The key technologies we have identified are largely immature. To assess their feasibility, cost and risk, further more detailed studies including Technology Demonstration Programmes (TDPs) are required.

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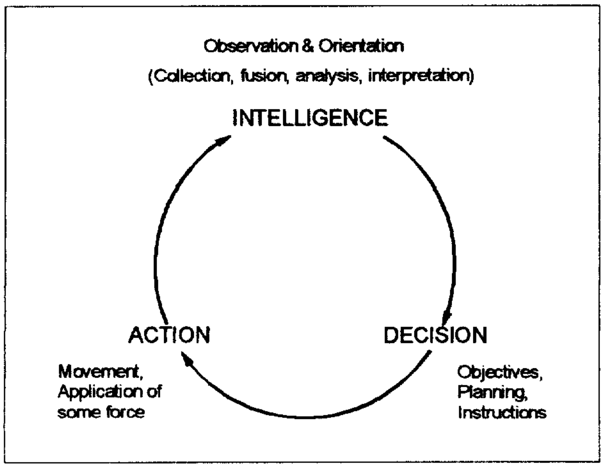
Appendix A: The Boyd Intelligence-Decision-Action (IDA) cycle.



The Boyd Cycle - Intelligence, Decision, Action

Boyd's Observation, Orientation, Decision, Action (OODA) cycle is now often referred to as the Intelligence-Decision-Action (IDA) cycle. It applies to any 'system' capable of some form of cognition, making a decision based on acquired knowledge, and taking some form of action to implement that decision. Any such system (human, animal or machine) looking to achieve an objective will go through this cycle. The IDA cycle is described below and is summarised in the diagram above.

The Intelligence Phase

The cycle notionally begins with the Intelligence phase and is equivalent to Boyd's Observation and Orientation phases. It involves the following functions:

- Gathering information (usually involving some form of sensing)
- Processing of the information to arrive at a perception of the situation confronting the system
- An evaluation of how the perceived situation may evolve with time

Intelligence also includes the assessment of the system's own state and how it may change. The product of the Intelligence phase might be termed 'situational awareness'.

The Decision phase

Based upon its perception of the situation confronting it and its own state, the system will decide on some aim or objectve. The system will then formulate a plan of action to achieve the objective.

The Action Phase

The plan of action is implemented, typically through a movement or an application of some form of force.

Note, that for most systems the element responsible for the Intelligence function will continue to operate while the Decision and Action phases are undertaken. Furthermore, in many instances a system will need (or choose) to achieve a number of 'intermediate' objectives in order to achieve its final aim. It will therefore go through a series of IDA cycles on its way to achieving the ultimate objective.

Appendix B: Figure 2: Typical Composite Air Operation