Chapter 13 – UK-1: DYNAMIC AIRBORNE MISSION MANAGEMENT

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13.1 DATES

This chapter concerns the series of technology demonstrations and test and evaluation trials conducted under the United Kingdom (UK) Ministry Of Defence (MOD) Dynamic Airborne Mission Management (DAMM) research programme. DAMM is a set of principles, interfaces and interactions for the delivery of effects, enabled by advanced digital networking and mission enabling technologies, providing a distributed, collaborative and adaptive mission capability for stability and dominance in a dynamic environment. The research was performed by UK Defence Industry, led by QinetiQ, with other Industry participants, including Thales, BAES, General Dynamics and Augusta/Westland. The research was performed under the DAMM Capability Concept Demonstrator (CCD) research programme, with underpinning research provided under the MOD Applied Research Programme (ARP), Research Entity (RE) 314, Mission Enabling Technologies and Demonstration (MET&D). The work was sponsored by MOD Cap TA (Capability – Theatre Airspace) and contracted through DE&S FBG-3 (Defence Equipment and Support, Future Business Group), with programme support technical advice provided by MOD Defence Science and Technology Laboratory, Air Weapons and Systems Department (DSTL AWSD). International Research Collaboration (IRC) on DAMM was conducted between MOD/Dstl and United States (US) Air Force Research Laboratory (AFRL), 711th Human Performance Wing (HPW), Human Effectiveness Directorate (HEC), Warfighter Interface Division, under the auspices of the US-UK Project Arrangement (PA), Network Centric Strike Controllers (NCSC).

The UK MOD DAMM CCD programme with QinetiQ commenced on contract in December 2008, with completion of Phase 3 scheduled for July 2011. The underpinning UK MOD research programme RE314 MET&D with QinetiQ provided Mission Management System (MMS) technical work and risk reduction for DAMM CCD throughout this period, with Synthetic Environment (SE) trials and technology demonstrations.

The DAMM CCD programme was conducted over 3 years, and divided into three phases, as illustrated by the Command and Control – Mission Management (C2-MM) architecture in Figure 13-1. Each phase advanced the degree of DAMM architecture complexity and built upon the previous phase to demonstrate enhanced capability:

- Phase 1, YR1 (2008 – 2009) Demonstration of baseline DAMM architecture including a Fixed Wing (FW) Tactical Fast-Jet (TFJ) package co-ordinated by a C2 element.
- Phase 2, YR2 (2009 – 2010) Integration of Rotary Wing (RW) MMS into the Phase 1 architecture and demonstration of rapid re-planning between assets in close support of land forces.
- Phase 3, YR3 (2010 – 2011) Integration and demonstration of an autonomous Uninhabited Air System (UAS) element to the Phase 2 for co-ordinated targeting capability.

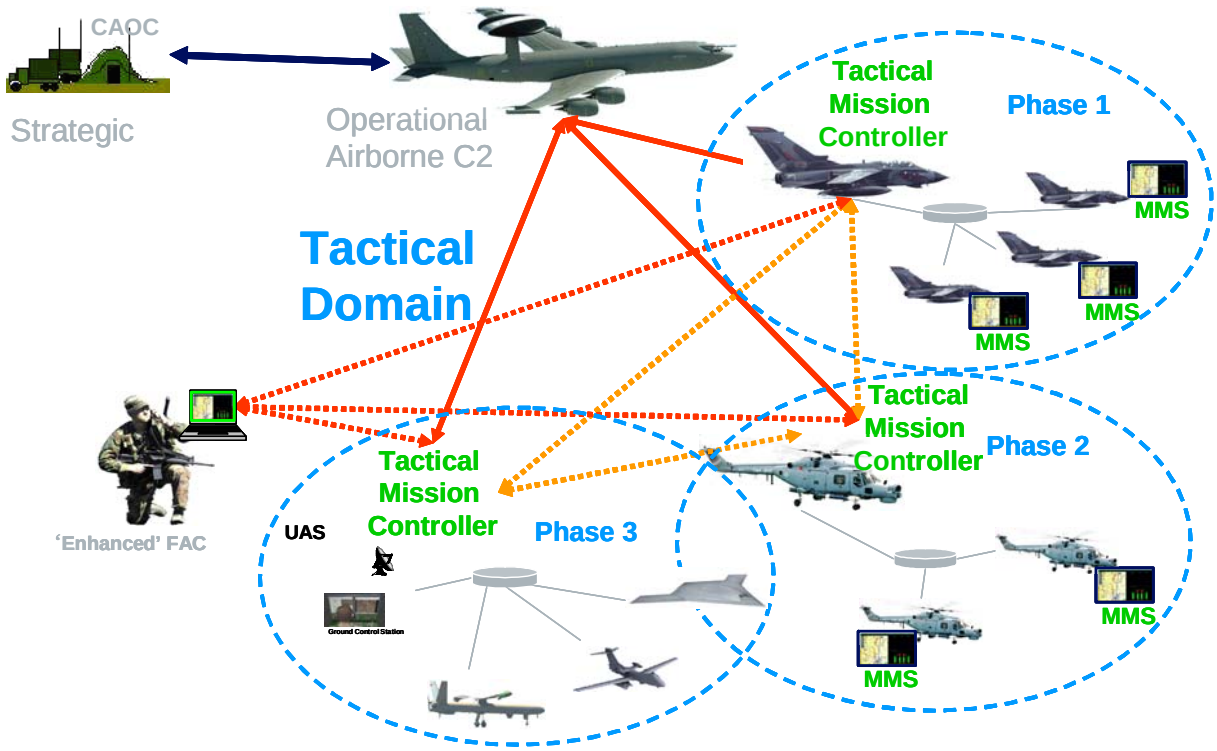


Figure 13-1: DAMM C2-MM Architecture.

Under RE314 MET&D and DAMM CCD, over ten technology demonstrations, SE and flight trials were completed in total; the four activities involving UAS components, reported here, were as follows:

- RE314 MET&D Joint US-UK SE Trial, September 2010 – FW TFJ and RW AH/SH Inter-Flight Co-ordination with FAC/JTAC, C2 and UAS.
- DAMM CCD UAS SE Technical Demonstration, April 2011 – UAS Co-ordination with RW SH, FW TFJ, C2 and FAC/JTAC.
- RE314 MET&D Joint US-UK SE Trial, July 2011 – Multiple UAS Co-ordination with RW SH, FW TFJ, C2 and FAC/JTAC.
- DAMM CCD RW Flight Trial, August 2011 – RW AH and RW SH Co-ordination with FW TFJ, C2, UAS and Deployed FAC/JTAC.

13.2 LOCATION

RE314 MET&D and DAMM CCD were UK Ministry of Defence research programmes managed by Dstl AWSD from Farnborough (2001 – 2009) and Portsdown West (2009 – 2011) in Hampshire UK. The work was performed under contract with QinetiQ Mission Management Group, based at Farnborough, Hampshire, UK. Technology development, laboratory studies and SE trials were conducted at QinetiQ Farnborough; flight trials were conducted in various UK airspace geographic locations.

13.3 SCENARIO/TASKS

DAMM comprised the following tactical mission capabilities:

- Airborne re-planning/modification of a pre-planned mission in response to dynamic events;
- Airborne plan formulation for missions which cannot be planned in advance; and
- Airborne co-ordination and de-confliction of multiple packages with a mission and between multiple missions.

RE314 MET&D and DAMM CCD focused on air-to-ground missions with increasing emphasis on improved air-land integration. Each phase included increased integration levels with relevant C2 and Intelligence Surveillance Target Acquisition and Reconnaissance (ISTAR) systems.

- **Tactical Fast Jet (TFJ) Scenario** – Unplanned Time Sensitive Target (TST) and Close Air Support (CAS) mission co-ordinated with Suppression of Air Defence (SEAD) support; C2 (Combined Air Operations Centre (CAOC) / E3 AWACS) to TFJ co-ordination (Figure 13-2).

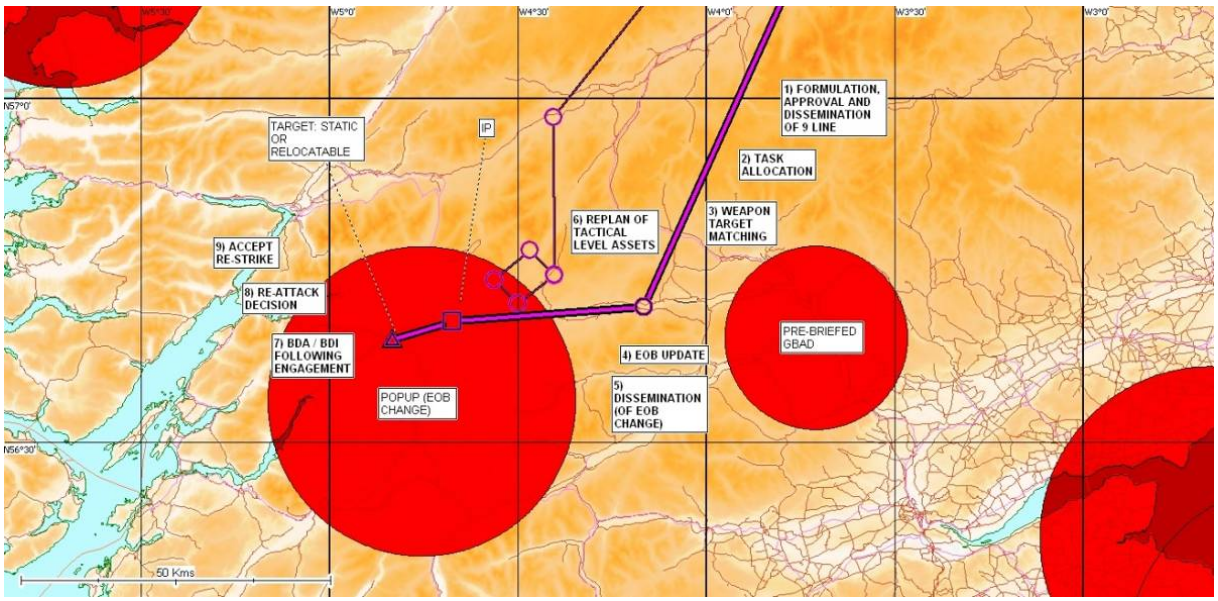


Figure 13-2: DAMM TFJ SE Trial NDZ Scenario Routes, Threat Locations and Decision Points.

- **Rotary Wing (RW) Scenario** – Stop and detainment of leadership target, co-ordinated with Joint Terminal Area Control (JTAC) / Forward Air Control (FAC) and TFJ support; C2 to helicopter MMS and TFJ co-ordination; Joint Personnel Recovery (JPR); Dynamic digital reallocation of airspace.
- **Uninhabited Air Systems (UAS) Scenario** – Providing ISTAR capability extension of the RW scenario, with reconnaissance, observation, and overwatch; TFJ CAS/TST co-ordination.

DAMM development used a validated Joint Warrior military scenario based on a NATO Joint Training Exercise (Joint Combat Aircraft / Maritime Integrated Systems Capability). This Joint Warrior scenario provided military realistic assets and a validated Air Tasking Order (ATO) and Airspace Co-ordination Order (ACO). The fictional scenario involved geo-political tension and the early phase of an escalating conflict

between adjacent national interests with disputed border regions. Neighbouring Nation states, named Avalon, Caledonia and Dragonia, were in dispute over two territorial zones , with the Northern Disputed Zone (NDZ) set for convenience in Argyll in the north-west Scotland, and the Southern Disputed Zone (SDZ) in Wiltshire and Somerset in south west of England. Scenario missions were operations of a multi-national coalition force assembled to maintain stability with backing by United Nations Security Council Resolutions (UNSCR). Coalition forces operated against insurgents, threats and covert activities (e.g., weapons importations and movements), with intelligence on High Value Targets (HVT). Coalition operations involved insertion and extraction of forces and the maintenance of logistical support. The Coalition had air superiority within the disputed airspace. Coalition operations had defined political and geographical settings (POL-MIL), Areas Of Responsibility (AOR), and monitored enemy Order of Battle (ORBAT), including re-locatable air defence units threatening operations close to borders and within disputed territory. Missions were briefed with Package composition, Commanders Intent (e.g., increasing stability in AOR) and Rules Of Engagement (ROE), with discrete operational phases (e.g., seize initiative, dominate).

In planning the scenario mission, a balance was sought in between the requirements of operational realism and the need to exercise and practice the DAMM tools. Consideration was given to factors influencing the dissemination of command intent, operational and tactical task evaluation and task allocation, and tactical mission management. Factors assessed included objectives to accomplish, threats to success, environmental factors, ROE, and agility. This analysis was used to elicit prioritisation of key mission system stressors across aircraft roles, judged as likely to be mitigated by tool usage, and significantly impacting on dynamic mission effectiveness. The generic mission stressors identified and employed in the scenarios were as follows:

- Electronic Order of Battle (EOB) Change;
- Ability to Interoperate (Communications);
- Force Intent Change;
- Force Capability Degradation;
- Weather; and
- ROE Change.

Scenarios and tasks, with stressing decision points (e.g., Figure 13-2), employed for development and testing used appropriately realistic operational contexts, with representative C2 system architectures, current Concept of Operations (CONOPS) and Concept of Employment (CONEMP), Standard Operating Procedures (SOPs), Special Instructions (SPINS) and ROE. Qualified and experienced serving military commanders and operators were used as military advisors and test participants to ensure best use of current military procedures, tactics and planning assumptions.

13.4 TECHNOLOGIES EXPLORED

DAMM CCD integrated mature MMS developed under the RE314 MET&D underpinning research programme. DAMM MMS comprised Situation Awareness (SA) tools, collaboration aids and decision support techniques, across dissimilar platform types, exploiting and advancing research conducted within FJ, RW and UAS domains. These MMS were further integrated with C2, ISTAR and ground-force elements to demonstrate the benefits and effectiveness of near-term airborne Network-Enabled Capability (NEC) using current data link technology. A key component of the NEC is information management, including maximizing effective use of available radio frequency spectrum and Human Machine Interface (HMI) which supports current doctrine and operational methods.

The CCD demonstrated and evaluated architectures for enabling DAMM at the tactical level including:

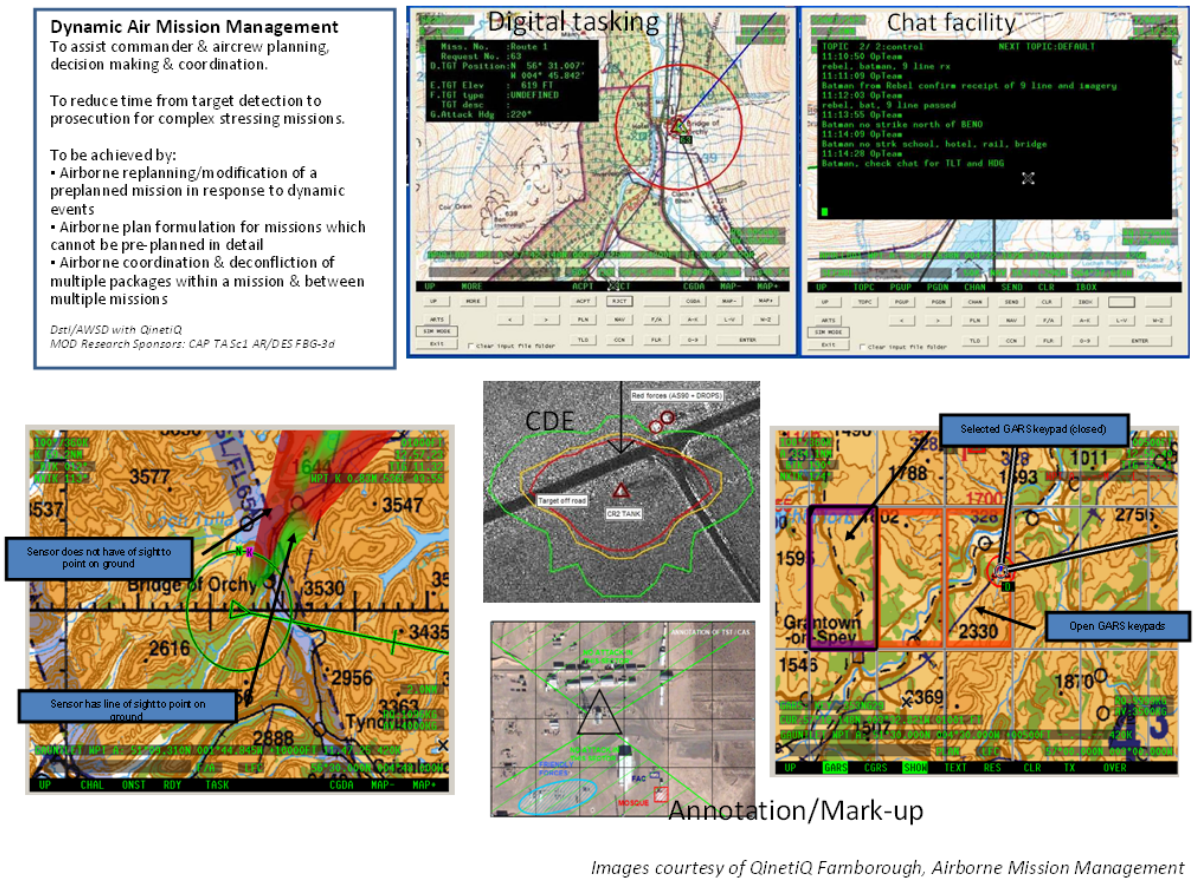
- Identification of information management issues and development of strategies that make the most of the effective use of the available bandwidth; and
- Information Exchange Requirement (IER) understanding/development leading to definition of bandwidth efficient protocols and Interface Control Definitions (ICD).

In terms of Technology Readiness Levels (TRL), the RE314 MET&D research programme raised relatively low TRL, early concept prototype development work (TRL 1 – 3) to TRL 5 by demonstration in a representative SE environment. TRL 5 was the entry level for MMS technology insertion into the DAMM CCD programme for flight trial demonstration and for raising to TRL 7.

The DAMM sub-system spans the Operational and Tactical C2-MM layers. DAMM is based on a three tier C2-MM architecture designed to provide sensible and adaptive spans of control needed for tight dynamic tactical co-ordination. The three tiers differ in the roles and functionality provided, and the kinds of decision support tools needed. The three tiers and associated tools are identified as follows:

- Tier 1 Operational C2 Level – Ground (e.g., CAOC) or airborne (e.g., AWACS E-3) C2 nodes: OpTEAM – Operational Task Evaluation and Authorisation Manager.
- Tier 2 Tactical C2 Level – Mission Commander, Package Commander: TacTEAM – Tactical Task Evaluation and Authorisation Manager; DESCAT – Digital Exchange System for Control and Targeting FAC equipment.
- Tier 3 Effector Levels – Flight formation members: TDSS – Tactical Decision Support System; OMPS – Rotorcraft TDSS On-board Mission Planning System; UAS Ground Control Station (GCS).

OpTEAM, TacTEAM and TDSS comprised different sets of DAMM MMS networked SA tools, collaboration aids and Decision Support System (DSS) techniques, as needed for supporting tactical co-ordination and decision making at the three tier levels. Examples of the DAMM tools are illustrated in Figure 13-3.



Images courtesy of QinetiQ Farnborough, Airborne Mission Management

Figure 13-3: Examples of DAMM Networked SA Tools, Collaboration Aids and Decision Support System Techniques.

OpTEAM provided the Tier 1 Operational C2 layer (CAOC/AWACS E3) with the following tool features (Figure 13-4):

- Map display; multiple map types; zoom options; lat long read out, distance measures and unit conversion; cultural, aeronautical and tactical overlays; multiple display options (e.g., de-clutter); inter-visibility analysis; the ability to create and review mark-up.
- Datalink capability (real and simulated); ATO and ACO import and display (along with other IER data feeds); digital Global Area Reference System (GARS) airspace de-confliction and management; chat facility; current position of assets; positions of threats, targets, forces, and wingmen.
- Routing information (for multiple assets and packages); route editing capability; route de-confliction; route timing information; route rehearsal and three dimensional (3D) fly through.
- Aircraft status; predicted fuel levels and tanking plans.

Figure 13-4: OpTEAM Supported Airborne Warning and Control SE Flying Desk.

Under DAMM CCD, Thales Air Systems Division provided an advanced web-enabled solution for OpTEAM C2 based on their WebS^{2}AT product with ATO/ACO visualisation, supplemented by the Recognised Air Picture (RAP) and feeds from the Joint Operation Picture (JOP).

The following tool features were provided by TacTEAM at the DAMM Tier 2 Tactical C2 layer, and by TDSS/ OMPS at the DAMM Tier 3 effectors layer (TFJ, RW) (Figure 13-5):

- Moving map display; multiple map types; zoom options; cultural, aeronautical and tactical overlays; multiple display options (e.g., brighten/dim screen, or show hide wingmen routings); the ability to review mark-up; inter-visibility analysis.
- Datalink capability (real and simulated); digital tasking; Planned Position Location Indication (PPLI); positions of threats, targets, forces, and wingmen.
- Routing information (for multiple assets and packages); route editing capability; route timing information.
- Aircraft status; chat facility; tactical decision support; Collateral Damage Estimation (CDE) visualisation and assessment.

Figure 13-5: TacTEAM Supported TFJ Weapons System Officer SE Flying Desk.

DESCAT 2 (Digital Exchange System for Control and Targeting) was provided to support the Forward Air Controller (FAC) or Joint Terminal Attack Controller (JTAC), operating at DAMM Tier 2 Tactical C2 layer (Figure 13-6). DESCAT 2 facilitated digital communications between ground and air assets, specifically the designation and allocation of targets to assets via the 9-line brief. The system capabilities and Windows XP-based user interface provided the following tool features and functions:

- Raster map display; Digital Terrain Elevation Database (DTED) terrain database height information; multiple map types; zoom options; multiple display options (e.g., brighten/dim screen, de-clutter); lat long read out, distance measures and unit conversion; tactical overlays; receipt and display of imagery, representative of UAS ROVER capability; ability to create and review mark-up; route forwarding; Collateral Damage Estimation (CDE) visualisation and assessment.
- Improved Data Modem (IDM) data-link protocols (TACFIRE, AFAPD, VMF), real and simulated; digital 9 line tasking; receipt, display and transmission of PPLI; positions of threats, targets, Blue forces; aircraft status, e.g., altitude; indirect target mensuration with GPS and Laser Rangefinders interfaces.
- C2 control interfaces with Joint Automated Deep Operations Co-ordination System (JADOCS) and Cursor On Target (COT) XML message set; local control, receipt, display and transmission of digital Global Area Reference System (GARS) airspace de-confliction and management messages; chat facility.

Figure 13-6: DESCAT 2 Supported FAC/JTAC.

Under the auspices of the US-UK NCSC / Strike Warrior II PA IRC programme, USAF AFRL provided the JTAC/FAC Battlefield Air Targeting Man Aided kNowledge (BATMAN) system for DAMM SE integration and testing with DESCAT 2. The BATMAN Bareback software application provided an electronic 9 line capability, with target data input via Laser Range Finder (LRF) or manually, using Speech Software with voice feedback, and friendly data input via Global Positioning System (GPS) or manually, with digital data transmission to CAOC. The BATMAN system provided operator aiding via Falconview mapping and terrain visualisation, with decision support information for the Special Tactics (ST) operator, and UAV tools. The system included a 3D audio and DRAW mark-up research capability.

UAS GCS, based on UK Watchkeeper (WK) Tactical Unmanned Air Vehicle (TUAV), provided the following functions and capabilities at DAMM Tier 3 Effectors layer (Figure 13-7):

- Moving map display; multiple map types; zoom options; cultural, aeronautical and tactical overlays; routing information (for multiple assets and packages); route editing, timing information, and route following capability; inter-visibility analysis; mark-up; multiple display options (e.g., brighten/dim screen, co-operating platforms routes); route assessment tools, e.g., threat envelopes, airspace constraints; target mensuration.

- Datalink capability (real and simulated); digital tasking; Planned Position Location Indication (PPLI); positions of threats, targets, forces, co-operating platforms; aircraft status.
- Real-time sensor video; sensor footprint overlay; vehicle controls, e.g., camera guide mode, auto-track mode.

Figure 13-7: UAS GCS Based on WK TUAV.

Current UAS operate as single platforms under Remotely Piloted Vehicle (RPV) control. With more autonomous UAS systems, it is likely that the operator will be controlling multiple UAVs, using for example a goal-oriented, service request-based approach. A multi-UAS GCS operator could be considered as operating more at the DAMM Tier 2 Tactical C2 layer.

A C2-MM capability scale was used to summarise the technologies involved and the impact of capability enhancement, as shown in Table 13-1 below. This capability maturity scale provides levels coupling network communications and collaborative decision support technologies and interfaces for C2-MM. The DAMM programme spanned Level 2 (DAMM Baseline architecture) to Level 4/5 (DAMM Objective architecture).

Table 13-1: Levels of Capability Maturity for C2-MM.

C2-MM Capability Level	Communications	Mission Management Decision Support
1	Voice Radio	No onboard integrated planning tool – Aircrew unsupported (re-planning and reactive)
2	Legacy Data Link (Limited message set)	Limited or no onboard planning aid, limited or no onboard collaboration tools, co-ordinated planning and co-ordination by voice
3	Legacy Data Link (Enhanced Message Set (EMS))	Intra-flight MM, adaptable decision support, co-ordinated machine-machine planning within package
4	Legacy Data Link (EMS)	Inter-flight MM within and across missions, adaptable decision support, fully integrated with operational C2 (year 1 DAMM)
5	Legacy Data Link (EMS) 5th-Generation Capability	Full adaptive/adaptable MM, dynamic battle management supported by (limited by) legacy data link. Cross-domain (air and land) dynamic co-ordinated planning.
6	Advanced Data Link	As above, but high capacity ad hoc network, agility, scale, richness
7	Advanced Data Link	As above, with pro-active Decision Support System

13.5 HUMAN FACTORS ISSUES EXPLORED

DAMM enables the provision of capability that is efficient and effective in a complex dynamic tactical environment. Complex high tempo operations, such as TST, CAS, SEAD and JPR, require persistence and urgency, and need rapid co-ordination and collaboration, both within and between mission packages, to deliver complex effects and ensure mission success. Critically, a DAMM collaborative capability is needed to provide operational flexibility, versatility and adaptability, enabling responsivity to rapidly changing mission requirements and dynamic events, such as re-tasking or threat changes. A collaborative and adaptive DAMM capability requires important Mission Essential Competencies (MEC), involving interpretation of command intent, rapid situation assessment, re-planning and communication, all with decision making for decision superiority at the core. Thus, the main Human Factors (HF) research thrust under DAMM was improving Critical Mission Decision Making (CMDM) in a distributed, collaborative, adaptive environment.

The HF issues of primary interest concerned understanding the requirements for aircrew interactions and interfaces needed for improving collaborative CMDM, and the development of applicable analytical tools and techniques for DAMM requirements capture, design, development, testing and evaluation. The focus was on the Operator-Mission Interface (OMI), and on the mission system functional and cognitive requirements, rather than on HMI ergonomics. Relevant OMI issues included the following: mission plan co-ordination and critiquing;

the centralisation, distribution and hierarchical structure of mission command flows; the communication and interpretation of command intent; prioritisation of mission critical decision information.

Specifically, the HF issues explored under DAMM were concerned with the following: developing HF methods for capturing user functional and information requirements for OMI CMDM in a distributed networked environment using SE technical demonstration testing and flight trials; modelling and measurement of the effects of highly networked MMS mission enabling technologies OMI, and associated collaboration and decision support tools, on CMDM; understanding and supporting CMDM processes at the tactical level, with cross-capability applicability, and within the broader system-of-system and C2 context; understanding the impact of C2-MM technologies on Mission/Tactical Director (TD), Mission Commander (MC) and Package Commander (PC) roles and responsibilities, and Mission Essential Competencies (MEC).

Requirements for CMDM processes involved in DAMM task MECs needed investigation, such as the following 9 CAS/TST examples:

1) Formulation, approval and dissemination of 9 Line;
2) Task allocation;
3) Weapon target matching;
4) EOB update;
5) Dissemination of EOB change;
6) Re-plan of tactical level assets;
7) Battle Damage Assessment (BDA) / Battle Damage Identification (BDI);
8) Re-attack decision; and
9) Accept re-strike.

Throughout the DAMM demonstration programme, trial planning and analysis prioritised the identification of scenarios and vignettes with operationally significant CMDM events and triggers. This was to provide valid and relevant use cases for testing the DAMM CMDM tools in a realistic operational context, with current SOPs, ROE, CONOPS, and C2 system architectures.

So, the HF challenge was to develop and exploit HF frameworks and protocols appropriate for highly networked, distributed, collaborative, adaptive DAMM CMDM assessment, and to support modelling and measurement of DAMM CMDM to improve utility and scientific robustness, i.e., improved validity and reliability, sensitivity and discrimination, diagnostic and prognostic power.

Development of DAMM capability, and development of the DAMM CMDM assessment approach, needed to be sensitive to the following: mission context, particularly the changing conditions on the ground; command intent and ROE; exchange of relevant SA information.

DAMM capability development needed to deliver timely Network Enabled Effects in response to dynamic events, such as the following: reducing time from task nomination-to-effect delivery; reducing the time from target detection to prosecution; co-ordinated and planned Time On Target (TOT exchange); accuracy and precision in CDE and BDA/BDI.

Development of the DAMM CMDM assessment approach needed to improve requirements capture and analysis, and improve assessing the effectiveness of collaborative decision support tools. Applicable methods

considered included: models and metrics for individual, team and organisational decision making; C2 Measures of Performance (MoP); C2 Measures of Effectiveness (MoE); system-of-systems views and system architecture representations of decision making derived from MODAF/DODAF system architect tools.

The strategy for DAMM CMDM assessment development was to extend traditional HF metrics of speed and accuracy, SA and workload, and to develop models and metrics of decision quality, teamwork and C2-MM system effectiveness, such as dynamic efficiency.

13.6 UNMANNED SYSTEMS USED

The DAMM research programme informed understanding of the requirements for current and future autonomous UAS to support DAMM capability. In particular, the work sought to understand the implications of UAS for the DAMM architecture, CONOPS and SOPs. Integration of UAS requirements into the DAMM architecture commenced in September 2010 under Phase 3 of the programme. In Phase 3, a UAS capability and GCS was integrated into SE work, and associated MMS into the DAMM architecture, based on the UK WK TUAV.

Thales is the primary UK supplier of UAS capability in-theatre. Currently, this is in the form of standard Hermes 450 air platform under the Lydian programme working closely with Sea King ASaC. This is coupled in-theatre with RAF operated, General Dynamics supplied, Predator/Reaper air platforms. Hermes 450 is soon to be replaced by the Thales WK system. Thus, WK will become a significant element of the UK's ability to provide ISTAR in-theatre. Currently, the contracted WK system includes an Improved Data Modem (IDM) data link, and ROVER video down-link. Building on this WK sensor and data link capability, the DAMM system sought to provide further digital networked co-ordination between WK and C2 assets (E3 AWACS), other tactical air platforms (RW Support Helicopter (SH) and Attack Helicopter (AH); FW TFJ strike aircraft), and FAC/JTAC air-land integration assets. WK with DAMM enabled capability has the potential to provide in-theatre real-time ISTAR, including cross-cueing of one asset from another using DAMM digital messages, enabling rapid and accurate dissemination of sensor tasking between assets, shortening reaction times, enabling more contacts to be investigated, and effects to be delivered more rapidly, with potentially life saving consequences. The work demonstrated co-ordinated mission planning and execution between manned and unmanned platforms as part of complex missions. The simulated WK TUAV with IDM data link provided ISTAR capability including the cross-cueing of one asset from another, using digital messages, and investigation of the utility of direct Full Motion Video (FMV) feeds from WK with ROVER video down-link (Figure 13-8). This final phase of the DAMM programme continued to progress TFJ to RW integration, as well as air-land integration through FAC/JTAC capability. Op-TEAM, Tac-TEAM and platform MMS incorporated additional tactics required to conduct Phase 3 missions with UAV elements.

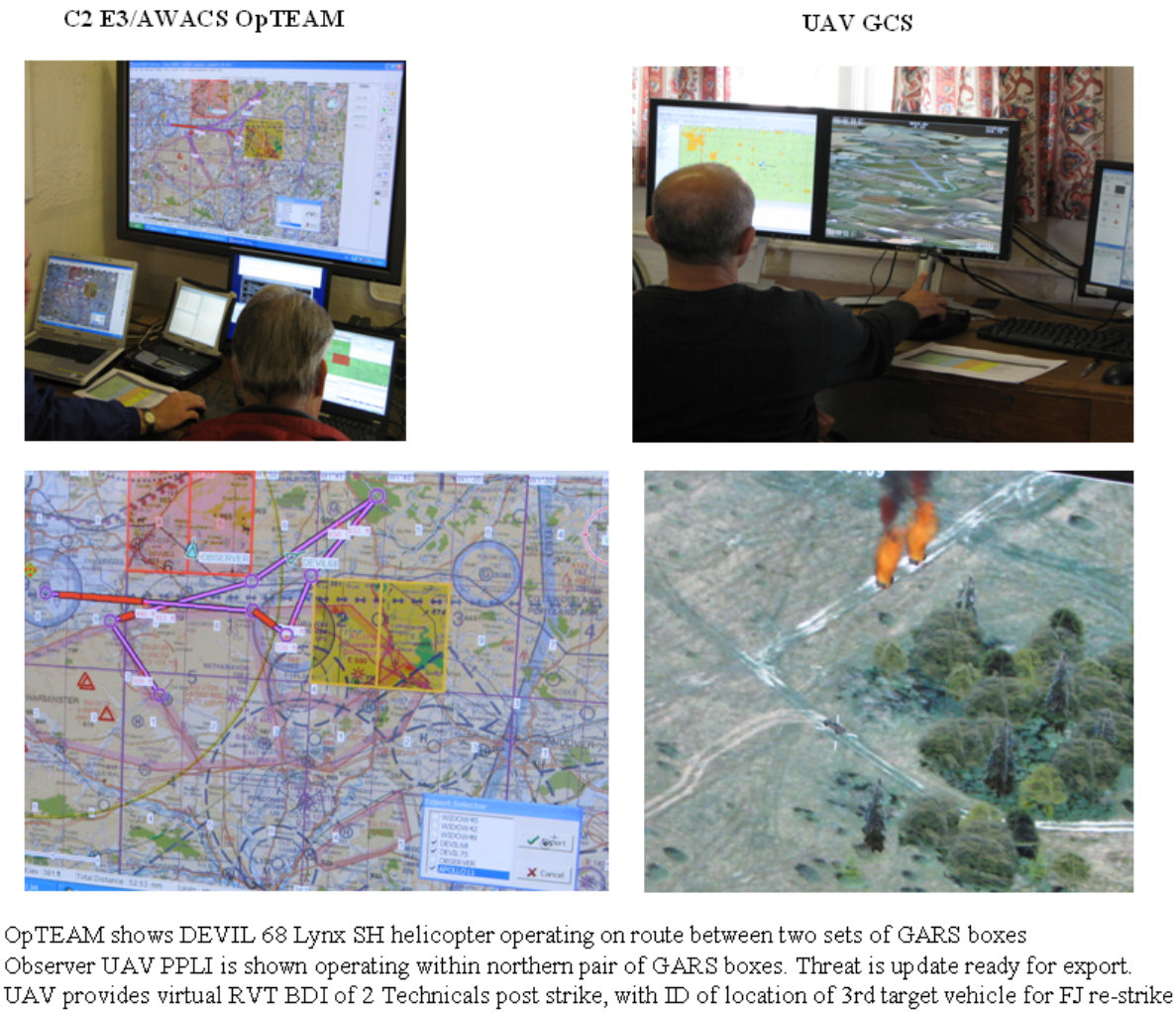


Figure 13-8: C2 Co-ordination of RW Support Helicopter, UAV and Fast Jet.

In parallel with WK TUAV GCS integration, under the auspices of the US-UK NCSC / Strike Warrior II PA International Research Collaboration (IRC) programme, USAF AFRL provided the Multi-UAV Supervisory Control Interface Technology (MUSCIT) Vigilant Spirit GCS and UAS system for integration and testing in the DAMM SE environment. This was used for investigation of advanced UAS capabilities and concepts in the RE314 MET&D UAS Integration SE Trial, July 2011 (Figure 13-9). MUSCIT / Vigilant Spirit is a single operator/multiple TUAV (x4) system, providing UAS ISTAR capability using a goal-oriented, service request-based approach to the provision of imagery. The MUSCIT / Vigilant Spirit GCS delivers UAS imagery on-demand through real-time sensor feeds to individual DAMM assets. Individual TUAVs providing the sensor feeds are managed by the GCS, through routing optimisation processes that are transparent to the originators of service requests. By introducing this supervisory control approach for a multiple TUAV system, compared with UK WK TUAV GCS, the integration of the USAF AFRL MUSCIT / Vigilant Spirit UAS GCS through IRC enabled the DAMM research programme to investigate the effects of UAS GCS working more at the DAMM Tier 2 Tactical C2 layer.

Figure 13-9: USAF AFRL MUSCIT / Vigilant Spirit TUAV GCS in DAMM SE.

The focus of the DAMM programme was on de-risking near-term UAS exploitation. In a complementary research activity, briefed and demonstrated to NATO HFM-170, MOD/Dstl sponsored a joint Industry advanced UAS research programme with QinetiQ, BAES and Thales entitled Autonomy and Mission Management (A&MM). The A&MM research programme investigated advanced UAS concepts for airspace and mission management with a focus on relatively low TRL development. The A&MM programme covered integration of tactical UAV (Thales WK TUAV) and operational UAV (BAES MANTIS OUAV) capabilities, and included the QinetiQ Task Execution Framework (TEF) for increasing UAV autonomy of heterogonous UAS ISTAR assets. The TEF approach uses goal-based tasking, “person-to-purpose” HMI, and agent oriented software-based planning solutions for optimised task allocation, co-ordination and routing. In this A&MM work, a Service-Oriented approach to the provision of UAS services is investigated, moving away from current process of tasking specific sensors/weapons on specific platforms to collect intelligence or deliver effects, and moving towards a more ‘Internet Protocol cloud-based model’. A&MM programme aspirations include the integration of autonomous software on the European Common Operating System (ECOS) architecture, and the development of a common ASAC three-layer stack architecture (Hardware, Common Operating System and Applications layers) for UAS control.

13.7 SUMMARY OF ANY NATO COMMUNICATIONS/COLLABORATIONS/ INTERACTIONS

The DAMM research programme focuses on UK specific requirements. Reports on DAMM status and progress were routinely communicated to NATO through HFM-170 meetings. Involvement of NATO Nations occurred at a number of levels.

US AFRL – Direct US involvement under RE314 underpinning SE work has been achieved through bilateral US-UK NCSC / Strike Warrior II PA, between MOD Dstl and US AFRL 71/HPW/HEC/Warfighter Interface Division, based at Wright Patterson AFB, Dayton Ohio. This provided integration of AFRL capabilities into three RE314 MET&D US-UK Strike Warrior II SE Trials, including Multi-Modal Communications (MMC), 3D spatial audio, US JTAC Batman capability imagery mark-up enhancements, and UAS MUSCIT Vigilant Spirit GCS.

Under HFM-170, discussions on DAMM UAS planning, concerning supervisory control and HF assessment issues, have been held with AFRL 711/HPW/RHCI (Dr. Mike Patzig / Dr. Mark Draper) on the MUSCIT programme and Vigilant Spirit GCS. This was supported by the MUSCIT multi-UAV (x4) flight demonstration at Camp Atterbury, Indiana on 5 May 2010.

US-UK PA collaboration facilitated by HFM-170 discussions, led to successful integration of MUSCIT / Vigilant Spirit GCS capability into the RE314 MET&D 3rd US-UK Strike Warrior II UAS Integration SE Trial, July 2011. US-UK IRC enabled the DAMM research programme to investigate the effects of UAS GCS supervisory control working at the DAMM Tier 2 Tactical C2 layer.

A new PA on UAS, entitled “Monitoring and Controlling Multiple Assets within Complex Environments” (MC-MACE), has been developed between AFRL 711/HPW/RHCI and MOD Dstl, lead by Brian Donnelly / Dr. Mark Draper (US) and Robert Taylor / Antony Grabham (UK). The MC-MACE PA is a multi-Nation programme of co-ordination under The Technical Co-operation Programme (TTCP), Human Resources and Performance (HUM) Group, Technical Panel 7, Human Systems Integration – Air. This TTCP HUM TP7 PA will provide increased international research collaboration on UAS programmes involving DRDC Canada and DSTO Air Operations Division, Australia, in addition to US and UK. The PA will support new UK work on Autonomy and Mission Systems, focussing on manned-unmanned teaming issues, including autonomy and mission management, collaborative autonomy and cohesive collaborative control capability.

US Army / NASA – US Army / NASA (Jay Shively) provided advice on RW scenarios, Playbook and UAS issues for the RE314 US-UK Strike Warrior II SE Trials, at a planning meeting held in San Francisco, USA in May 2009.

Sweden FOI – Discussions with Sweden FOI FLSC and UK MOD/Dstl under the UK-SWE MOU, and supported by HFM-170, have led to planning of a joint UK-SWE project (Project CODE) on distributed mission simulation and synthetic training with Live Virtual Constructive (LVC) capability. A meeting between MOD Dstl (Bob Taylor / Ebb Smith / Robert Anderson) and FOI FLSC (Jonathan Borgvall / Lars Kristensson / Martin Castner) was held at FLSC on 3-4 March 2010 to develop scenario vignettes. The scenario will involve network linking of SE facilities at FLSC Stockholm with the UK MOD Air Battle Training Centre (ABTC) at RAF Waddington. The first UK-SWE Exercise SNOWSTORM is planned for June 2011. SNOWSTORM will focus on synthetic training requirements for operational DAMM capability.

France DGA / Telecom Bretagne – Arising from meetings under HFM-170, bi-lateral meetings between UK and France on DAMM UAS capability and HF research requirements, have been held in UK (4 December

2008, Farnborough) and France (1-2 April 2009, Brest) between Institut Telecom / Telecom Bretagne (Dr. Gilles Coppin) and France MOD/DGA (Mr. Didier Bazalgette) and UK MOD/Dstl (Robert Taylor / Antony Grabham). In parallel, a joint Anglo-French research programme on Autonomy and Mission Management has been agreed commencing 2010. The aim of this collaboration is to ultimately develop a joint SE capable of allowing dissimilar UK and French autonomous UAS to interoperate within the simulated battlespace to carry out multiple missions controlled by a limited number of operators.

Australia DSTO AOD – Under the auspices of TTCP (HUM TP7/TP2), DSTO Australia, Air Operations Division (POC Dr. Chris Best) had direct involvement in the RE314 MET&D 2nd US-UK Strike Warrior II SE Trial, September 2010, working with MOD Dstl and US AFRL 711/HPW.

Understanding of the implications for coalition and NATO joint operational requirements are potentially of interest for future work. The main area for NATO involvement was in the planning and design stages of the demonstration activities, with possibilities for involvement in analysis, as summarised in Table 13-2. There was potential for collaboration with NATO Nation's related efforts at the level of aims, objectives, approach, CONOPS, metrics, architectures, and in particular the application of HF lessons learned.

Table 13-2: NATO Collaboration for DAMM CCD.

	Planning/Design	***Execution***	***Analysis***
Communication	*x*	*x*	*x*
Co-ordination	*x*		*x*
Collaboration	*x*		*x*

In practice, NATO Nation's direct involvement in the execution of DAMM activities was difficult to achieve, due to the constraints, funding arrangements and complex nature of the project, and the UK specific requirements. Nevertheless, the DAMM network interfaces were considered 'open', and as such, NATO Nations could bring elements for integration into future demonstration activities. Collaboration through an SE trial is probably more readily achievable than through a joint flight trial.

13.8 SUMMARY OF DAMM UAS TECHNOLOGY DEMONSTRATION RESULTS

13.8.1 RE314 MET&D Joint US-UK SE Trial, September 2010 – FW TFJ and RW AH/SH Inter-Flight Co-ordination with FAC/JTAC, C2 and UAS

A 2nd in a series of Joint DAMM SE Trials was conducted with USAF AFRL at QinetiQ Farnborough in September 2010, under the US-UK NCSC / Strike Warrior II PA, with the aim of increasing Air-Land integration, and providing further development of collaboration performance measurement. This trial introduced a nominal synthetic UAS component for future capability development. The trial involved USAF aircrew and UK MOD serving military operators, with additional military participation provided by DSTO AOD Australia, under TTCP collaboration. The scenario was based on the previous FW/RW/C2 SE Trial, under Joint Warrior conditions, with increased FAC/JTAC involvement, and a nominal UAS reconnaissance capability. The expanded scenario comprised the following elements:

- 1 AWACS E3-D Airborne C2 with OpTEAM;
- 2/3 FAC/JTAC with digital targeting technology (DESCAT and/or BATMAN);
- 2 FW TFJ Ground Attack aircraft with TacTEAM/TDSS – one single seat aircraft emulating Typhoon capability (FWSS), and one twin seat aircraft emulating Tornado GR4 (FW2S);
- 2 RW aircraft – one RW AH and one RW SH – both operated by two aircrew with standard avionics (Baseline), stand-alone DIGIMAP (Threshold) or networked OMPS Technology (Objective); and
- 1 Reconnaissance UAS – Platform not represented but simulated sensor feeds provided via network to different nodes depending on Baseline, Threshold or Objective.

White Force Trial Control was provided with networked OpTEAM as SA and trials management tool. Functionality and networking varied depending on Baseline, Threshold or Objective. The trial aim was to examine the effects of C2-MM architectures and MC positions on crew decision making. Based on the Joint Warrior NDZ scenario, the missions involved a series of unexpected events requiring re-planning and mission critical decisions. These provided discrete decision making points for CMDM assessment. The geographic location was centred on the Invergarry / Fort Augustus / Loch Lochy area north-east of Fort William and Ben Nevis. The scenario involved co-ordination between land component and air component commanders prosecuting CAS missions and Time TST within a coalition context where coalition partners are undertaking pre-planned missions. Due to dynamic events, cross-co-ordination between the CAS/TST missions and the pre-planned missions that were originally under a separate AOR becomes necessary. The trial sought to improve understanding of the effects on mission command flow and locus of critical mission decision making, such as the balance of centralized versus distributed decision making.

The trial followed an experimental plan designed to test and compare three alternative C2-MM architectures – Baseline, Threshold and Objective – and three positions for Mission Commander (MC) – C2 , RW (AH), FW (SS and 2S) – with nine combinations of C2-MM architectures and MC positions operating over three days, with three different runs per day. The scenario was controlled by White Force and developed progressively during the trial runs in phases using three mission vignettes. Different events, threats and target behaviours were produced by WF, designed to maintain operator engagement and mitigate learning. Performance with the Baseline architecture was tested on the first trial run. The comparison architectures were tested on subsequent runs (Threshold x 3: Objective x 4), with the order balanced to control for learning.

DSTL SMEs provided assessments of performance and effectiveness based on identified CMDM critical decision points. These were obtained during post-run de-briefing sessions from participant self-ratings and SME observer scoring. Subjective ratings (7-point Low-High anchors, Likert scales) were obtained for 66 trial parameters in total. These comprised 21 participant CMDM self-ratings for identified critical decisions including REMDAER activity phase demand, 4T's change management demand, workload, SA and decision quality. For individual trial runs, participant ratings were obtained for tools usability (x19), and for generic system CONOPS and architecture assessment parameters (x12), including dynamic mission efficiency, teamwork and technical system performance. Additionally, ratings were obtained from SME observer on 14 assessment scales covering workload, decision making, dynamic efficiency and teamwork. Teamwork metrics included estimations of collaboration power and collaboration correlation, and new higher order measures of team collaboration co-efficiency, dynamic efficiency, and team adaptability proficiency. DSTO AOD conducted an independent assessment complementary process, including a CAS SME continuous assessment of CAS performance, captured on-line using a digital tablet-based protocol, and administered validated self-ratings of CAS Taskwork, Team Workload and Teamwork during post-run de-briefing.

Statistical analysis (ANOVA) of the DSTL assessment subjective ratings showed significant effects ($p<0.05$) of the Baseline (B), Threshold (T) and Objective (O) architectures as follows:

- Activity phase demand: Mitigation (B<T); Dissemination (B<OT) $p<0.05$ (NB Evaluation (B<T) $p<0.09$; Acknowledgement (B<T) $p<0.08$).
- 4T Change demand: Task, Threat (B<OT) $p<0.01$.
- Workload: Time pressure (B<OT) $p<0.01$; Mental effort, Stress (B<T) $p<0.05$.
- SA: Understanding (T<O) $p<0.01$.
- DQ: Confidence (T<O), Effectiveness (BT<O), Timeliness (B<TO) $p<0.001$.
- Dynamic Efficiency: Reward/Effort (T<O), Rate (B<O) $p<0.05$; Sustainability (BT<O) $p<0.001$.
- Team Work: Co-ordination, Co-operation, Collaboration, Communication, Leadership, Power (BT<O) $p<0.001$.
- System: Confidence (T<O) $p<0.01$; Reliability (B<O) $p<0.05$ (NB Usability (T<O) $p<0.07$).

In summary, there was some evidence that Baseline architecture evoked lower ratings of activity phase and change demand, and workload. Importantly, there was very strong evidence that the Objective architecture evoked significantly higher ratings of SA, DQ, Dynamic Efficiency and Team Work. The consistently high ratings for Team Work with the Objective architecture were the strongest differentiator from the Baseline and Threshold architectures. This is evidence that the enhancement of collective effort afforded by advanced DAMM technology is probably the strongest factor underpinning the improvements in adaptability proficiency and performance.

The results of the DSTL assessment contrasting the individual trial runs are summarised in Table 13-3 below. Improved adaptability proficiency, followed by improved dynamic efficiency, is hypothesised as directly underpinning improvements in performance and effectiveness on dynamic missions. Guided by this assertion, in Table 13-3, the data for the individual eight trial mission runs are presented in the position order (P 1-8) of the adaptability proficiency ratings provided by White Force SME assessors. The summation total of the adaptability proficiency ratings are reported first, followed by with the number of observations contributing to the total. Then, target performance (+ve/-ve) is shown, followed by an estimation of Decision Flow (Decision points, run time, decision tempo), Dynamic Efficiency (SME Observer and Participant ratings means), and Collaboration Co-efficiency (Power and Correlation estimates). Trial runs with the Objective (OB) architecture occupied P1/2/3/4/6. Threshold (TH) architecture runs are at P5 and P7. The Baseline (BA) architecture tested on Run 1 provided the lowest adaptability proficiency ratings and thus was positioned at P8. The pattern of adaptability proficiency results are generally supported by the metrics of decision flow, dynamic efficiency and collaboration co-efficiency. Run order, with associated learning effects, and Architecture condition, were partially confounded. Notwithstanding, the pattern of results overall is consistent with superiority for the Objective architecture. The pattern of target performance scores is complex and less clearly related to the architecture condition. Four MC positions were tested: FWSS; FW2S; RWAH; E3. MC position was partially confounded with architectures and run order. The effect of MC position on adaptability proficiency was complex. The MC role requires good communications and SA. On aggregate, based on adaptability proficiency, the FW positions appeared most favoured, and the E3 the least favoured positions (FWSS P1/6; FW2S P2; RWAH P3/7; E3 P4/5/8). The Objective architecture provided relatively good adaptability proficiency with the MC in all four positions, consistent with good communications and SA. Evidence from specific events and interventions on individual runs showed benefits of distributed and adaptive decision making, afforded most by the networked Objective architecture.

Table 13-3: Summary of Results from the 2nd US-UK NCSC / Strike Warrior II SE Trial.

P	Mission	Adaptability Proficiency		Targets		Decision Flow			Dynamic Efficiency		Collab Coeff	
		Total	Obs	+	-	Pts	Time	Tmp	Obvr	Part	Pwr	Corr
1	OB-FWSS-V3-R8 Bridge Stop West	48	8	4	0	36	26:00	0.43	6.00	5.43	5.71	5.05
2	OB-FW2S-V3-R7 Ugly North South	46	7	3	2	23	21:15	1.22	6.00	5.78	6.00	6.27
3	OB-RWAH-V3-R5 Late West	39	6	5	0	23	32:30	1.25	6.00	5.11	5.56	5.82
4	OB-E3-V2-R4 Bridge Stop North	27	4	4	0	18	28:00	1.33	5.80	5.37	5.62	5.85
5	TH-E3-V3-R6 Wrong Bridge	25	6	3	2	25	34:00	1.22	4.00	4.33	3.67	4.96
6	OB-FWSS-V2-R2 Pick-up JTAC	24	4	4	1	12	34:35	2.53	5.80	4.87	5.37	6.85
7	TH-RWAH-V2-R3 Support TIC	25	4	4	0	13	41:45	3.12	5.60	5.12	5.12	5.37
8	BA-E3-V1-R1 Abort Hard Stop	7	3	2	2	14	26:15	1.52	4.80	4.62	4.12	4.42

13.8.2 DAMM CCD UAS SE Technical Demonstration, April 2011 – UAS Co-ordination with RW SH, FW TFJ, C2 and FAC/JTAC

Under DAMM CCD Phase 3, work was undertaken with Thales to develop a UAS reconnaissance capability for integration and demonstration in DAMM trials, based on the UK WK TUAV, thereby de-risking near-term UAS exploitation of DAMM capability. Thales provided a representation of the WK GCS and a representation of the WK Full Motion Video (FMV) feed using a Remote Viewing Terminal (RVT) for demonstration at QinetiQ in a fully immersive environment. The UAS demonstration scenario was based on the Joint Warrior NDZ scenario used for the 2nd Joint US-UK SE Trial, centred on the Invergarry / Fort Augustus / Loch Lochy area of Scotland. The scenario involved a pre-planned deliberate operation, with a High Value Target (HVT) meeting at a known site, RW SH inserted capture, and a co-ordinated FW TFJ strike on arms cache. The assets and tasking were for a WK UAS over-watch on meeting site, FAC/JTAC control of FW TFJ strike, RW SH inserts ground forces to effect capture, FW TFJ time co-ordinated to attack while RW SH on ground, and C2 overall co-ordination and control. The DAMM mission enabling tools involved were OpTEAM, TacTEAM/TDSS, OMPS and WK GCS. The following event flow was successfully demonstrated in the QinetiQ SE facilities:

- Initial asset disposition as pre-plan, GARS airspace pre-allocated.
- HVT arrives, 3 vehicles scatter – WK reports to C2; HUMINT reports SIED north, HVT west, Arms transfer south.
- C2 calls abort – RW to hold; TFJ to hold; FAC/JTAC relinquishes airspace.
- C2 re-tasks WK to follow SIED – WK re-plans; WK publishes route.
- C2 re-plan – C2 assigns WK airspace; C2 re-tasks RW to pursue/stop SIED; C2 re-tasks TFJ to delay/ obstruct HVT.
- Assets execute re-plan – Shared SA through GARS, route, PPLI enables distributed re-planning and co-ordination of individual taskings.

In a second phase of work, the QinetiQ HOVERS SE was used to demonstrate the UAS RVT supporting representative RW SH operations in an immersive environment, with the Joint Warrior NDZ scenario centred near Fort Augustus, north of Loch Lochy in Scotland. In the UAS RVT demonstration, the RW SH operated with serving military aircrew, was tasked with short movement of ground troops to a known Landing Site (LS) to create and man a temporary road block, searching for small-scale movement of arms caches. Insurgents were known to have 4 armed "technicals". In the event, a moving vehicle departed the road, and arrived at the LS, co-incident with a White Force SAFIRE inject causing an RW SH direction change en route close to the LS. Two runs trial were flown, each with a pre-loaded route on an OMPS-based hand held DIGIMAP system. The first run was performed without the RVT capability. The second run was flown with the RVT capability. On the RVT run, a TUAV air vehicle, controlled from the WK GCS, was positioned to give a virtual RVT view of the LS. The participant aircrew assessments reported that Crew Resource Management issues concerning information interpretation were dependent on the individual aircraft receiving RVT, i.e., AH direct feed; RW SH to crewman or off-board UAS image analyst; live feed to SH embarked troops. It was considered that objective-based tasking (e.g., point sensor at location X) would most likely be more appropriate than attempting direct control of one or more UAS. Generally, SA was considered to be enhanced with live positional information from UAS in close proximity.

13.8.3 RE314 MET&D Joint US-UK SE Trial, July 2011 – Multiple UAS Co-ordination with RW SH, FW TFJ, C2 and FAC/JTAC

A 3rd in series Joint DAMM SE Trial involving USAF AFRL was conducted under the US-UK NCSC / Strike Warrior II PA at QinetiQ Farnborough in July 2011, with a focus on multiple UAS co-ordination. USAF AFRL provided the MUSCIT / Vigilant Spirit multiple UAS system and GCS for DAMM SE integration and testing. The trial involved UK MOD serving military operators and USAF aircrew, including US and UK UAV operations specialists. The scenario comprised the following elements:

- AWACS E3 Airborne C2 with OpTEAM;
- 2 FAC/JTAC with digital targeting technology (DESCAT and/or BATMAN);
- 1 FW TFJ Ground Attack aircraft with TacTEAM/TDSS;
- 1 RW SH using an immersive simulator (HOVERS) with networked DIGIMAP; and
- 4 Reconnaissance UAS.

USAF AFRL provided 3D audio cueing capability for moving target designation by FAC/JTAC and UAS. White Force / Trial Control were provided with networked OpTEAM as SA and trials management tool.

The trial was based on Joint Warrior NDZ scenario operations centred on the Invergarry / Fort Augustus / Loch Lochy area of Scotland, with increased UAS involvement in observation and reconnaissance. The scenario involved a pre-planned deliberate operation, with a High Value Target (HVT) meeting at a known site, RW SH inserted capture, and a co-ordinated FW TFJ strike on arms cache. The assets and tasking were for a SF FAC observation and UAS over-watch on an adjacent urban area for known HVTs, in addition to the meeting site, FAC/JTAC control of FW TFJ strike, RW SH inserts of ground forces to effect capture, FW TFJ time co-ordinated to attack while RW SH on ground, and C2 overall co-ordination and control. Trial White Force inserted information, events, threats and target behavioural changes requiring real-time re-planning and co-ordination. The trial took place over a period of 5 days, following a 4 weeks of extensive technical development, integration, and system and SE testing, and progressive scenario refinement. After completion of role specific training, the trial runs were conducted in two phases, with the first phase comprising tool use-case

vignettes and the second phase end-to-end scenario runs. All use cases and end-to-end runs involved active operator participation and decision making, post run de-briefing and performance measurement. DAMM tools were available for use on all the trial runs. The use-case runs provided additional training and focussed performance data on DAMM tool usage. Additionally, the use-case runs increased participant familiarisation with the DAMM tools applicability and benefits, in readiness for the end-to-end scenario runs. The scenario runs were developed progressively with changing and evolving complexity to maintain operator interest, engagement and to challenge DAMM competencies and tool usage. In total, 6 use-case vignettes and 4 end-to-end scenario runs were completed. The DSTL trial assessment included participant self-ratings and observer SME ratings obtained for use cases and end-to-end runs during post-run de-briefing sessions. Subjective ratings (7-point Low-High anchors, Likert scales) were obtained for 57 trial parameters in total.

Participants provided CMDM self-ratings on 17 parameters for individual identified critical decisions:

- Workload: WL Time Pressure, WL Mental Effort, WL Stress, Team Workload.
- Re-plan Task Load: Re-plan Decision (Recognise–Evaluate–Mitigate), Re-plan Action (Disseminate–Acknowledge–Execute–Report).
- Situation Awareness: SA Demand on Attentional Resources, SA Supply of Attentional Resources, SA Understanding.
- Decision Quality: DQ Confidence, DQ Survivability, DQ Effectiveness, DQ Timeliness.
- Performance: Task Performance, Tools Utility, Adaptability Proficiency, Probability of Mission Success.

Participants provided ratings on DAMM technical system performance for 25 items:

- Assessment of the relative usability of information and tools – 22 items in total divided into the 6 categories (Comms, Route, Position, SA, Task, UAS Services).
- Technical System General Performance: Confidence, Reliability, Usability.

Observer SMEs recorded observations and events with associated mission times, and provided ratings on the 15 parameters:

- Decision Quality: DQ Confidence, DQ Survivability, DQ Effectiveness, DQ Timeliness.
- Teamwork: Communication, Shared SA, Leadership, Support, Team Workload.
- Performance: Task Performance, Collaboration, Influence Power, Adaptability Proficiency, Probability of Mission Success.

Analysis of the results (ANOVA) comparing Observer and Participant ratings showed significant differences in the ratings of DQ Survivability, Effectiveness ($p<0.01$) and Timeliness ($p<0.05$), Adaptability Proficiency ($p<0.05$), and Probability of Mission Success ($p<0.01$), with significantly higher ratings provided by observers. Comparisons between ratings for decision events showed significant differences. Observer data showed significant differences between ratings of decision events within end-to-end runs for Shared SA and Team Workload ($p<0.05$), Adaptability Proficiency ($p<0.01$) and Probability of Mission Success ($p<0.05$). The Comparisons between the four end-to-end runs showed a pattern of higher ratings for the 2nd trial run. Overall, these results provide evidence in support of the use of Observer SME ratings.

Demand for UAS over-watch, reconnaissance and observation services varied continuously and reached high levels during dynamic phases and events. Deployment of the multiple UAS was stretched by the scenario.

Generally, the UAS were deployed effectively and efficiently via the MUSCIT / Vigilant Spirit GCS, with the UAV operator assessment ratings indicating good operator engagement and SA, and contributing significantly to maintaining mission SSA and command flow. Scenario emersion and workload was observed to be high for both the UAS GCS operator and JTAC/FAC. This was confirmed by AFRL-provided real-time physiological measures. Demand for UAS over-watch, reconnaissance and observation services varied continuously and reached high levels during dynamic phases and events. Deployment of the multiple UAS was stretched by the scenario. Generally, the UAS were deployed effectively and efficiently via the MUSCIT / Vigilant Spirit GCS, indicating high operator engagement and SA. UAS contributed significantly to maintaining mission SSA and command flow. Scenario emersion and workload was high for UAS GCS operator and JTAC/FAC. This was confirmed by AFRL-provided real-time physiological measures.

13.8.4 DAMM CCD RW Flight Trial, August 2011 – RW AH and RW SH Co-ordination with FW TFJ, C2, UAS and Deployed FAC/JTAC

This trial was an airborne demonstration of the Rotary Wing elements of previous RE314 SE trials with a deployed FAC/JTAC using the Joint Warrior SDZ operating out of AAC Middle Wallop and Westdown Camp. Two trial missions were flown as training sorties, followed by 4 trial sorties, flown with or without the networked architecture, conducted over a period of four days. This was followed by a fully networked visitor day demonstration. All trial runs involved DSTL provided performance measurement. The scenario involved the following components.

- 2 deployed RW Lynx aircraft with networked DIGIMAP;
- 1 deployed RW Apache AH (Day 4 only);
- 1 deployed FAC/JTAC with digital targeting technology (DESCAT);
- 1 simulated AWACS E3 Airborne C2 node with OpTEAM;
- 1 simulated FW TFJ Ground Attack aircraft with TacTEAM/TDSS; and
- 1 simulated Reconnaissance WK TUAV.

The DSTL provided trial assessment included participant self-ratings and observer SME ratings obtained during post-run de-briefing sessions. Subjective ratings (7-point Low-High anchors, Likert scales) were obtained for trial parameters using the protocols developed for the July 2011 Joint US-UK SE trial.

Participants provided CMDM self-ratings on 17 parameters for individual identified critical decisions:

- Workload: WL Time Pressure, WL Mental Effort, WL Stress, Team Workload.
- Re-plan Task Load: Re-plan Decision (Recognise–Evaluate–Mitigate), Re-plan Action (Disseminate–Acknowledge–Execute–Report).
- Situation Awareness: SA Demand on Attentional Resources, SA Supply of Attentional Resources, SA Understanding.
- Decision Quality: DQ Confidence, DQ Survivability, DQ Effectiveness, DQ Timeliness.
- Performance: Task Performance, Tools Utility, Adaptability Proficiency, Probability of Mission Success.

In addition, participants provided ratings of the relative usability on DAMM information and tools performance for 13 items in 6 categories (Comms, Route, Position, SA tools, Task).

Observer SMEs recorded observations and events with associated mission times, and provided ratings on the 15 parameters:

- Decision Quality: DQ Confidence, DQ Survivability, DQ Effectiveness, DQ Timeliness.
- Teamwork: Communication, Shared SA, Leadership, Support, Team Workload.
- Performance: Task Performance, Collaboration, Influence Power, Adaptability Proficiency, Probability of Mission Success.

In addition, SME observers provided ratings of the relative usability on DAMM information and tools performance for 13 items in 6 categories (Comms, Route, Position, SA tools, Task). Analysis of the trial results showed significant confounding of architecture conditions due to strong training/sortie order effects. Notwithstanding, for the networked sorties, there was evidence of a consistent pattern of lower workload ratings, together with significant improvements ($p<0.05$) in decision quality, team task performance, and adaptability proficiency. All the DAMM tools, apart from 1st Cut Time Distance Fuel and Route Timing Information scored very high on both Usability of Information and Tools and Utility of Functional Purpose.

In conclusion, the results of the trial provided high TRL evidence, proof and validation of the efficacy of the DAMM networked architecture and tools, of the DAMM principles, interfaces and interactions, and of the CONOPS and TPPs, integrated with a representative synthetic UAS reconnaissance capability component, through testing with real aircraft under realistic, live flight, operational mission conditions.

13.9 LESSONS LEARNED

13.9.1 Dynamic Airborne Mission Management

Evidence from the UK MOD DAMM research programme of technical demonstrations and test and evaluation trials on advanced digital networking and mission enabling technologies provides robust verification and validation of DAMM principles, interfaces and interactions for delivering effects and providing stability and dominance in a dynamic environment. DAMM technologies and applications are shown consistently to deliver an efficient and effective distributed, collaborative and adaptive mission capability. In summary, the DAMM programme provides evidence of the efficacy of the following:

- Advanced digital network technologies, operating within a multi-tier C2-MM architecture with operational and tactical layers, provides the high capacity ad hoc networking with the agility, scale and richness needed to maintain mission and command flow through intra- and inter-flight communication, cross-domain (air and land) integration, and integrated operational C2.
- Mission enabling technologies, coupled with advanced digital networking, provide the tools needed for intra- and inter-flight mission management, cross-domain (air and land) dynamic co-ordinated planning, and dynamic battle management:
  - Airborne re-planning/modification of a pre-planned mission in response to dynamic events.
  - Airborne plan formulation for missions which cannot be planned in advance.
  - Airborne co-ordination and de-confliction of multiple packages with a mission and between multiple missions.

13.9.2 UAS Integration

MoD requirements for a UAS DAMM enabled capability are the need for flexibility, agility and persistence for over-watch support and targeting. To achieve these requirements, the following is needed:

- Ability to co-ordinate airspace and missions between manned and unmanned platforms.

- Ability to rapidly task UAS.
- Ability to rapidly exploit the output from UAS.
- Support improved Shared Situational Awareness (SSA) with UAS.

This involved the identification, specification, development and implementation of DAMM Information Exchange Requirements (IER) and Interface Control Documents (ICD) for UAS requirements for airspace management, route data and Plan Position Location Information (PPLI).

In order to address the requirements for airspace management, under the DAMM programme, MoD have developed an electronic version of the Global Area Reference System (GARS) for airspace management. The reason for this is that GARS is the currently accepted standard used by NATO for managing theatre airspace. Air Battle Managers currently allocate airspace to operational users using height-banded air cells communicated by voice, and recorded manually by UAS operators by marking-up charts. Electronic GARS offers user benefits for speed, accuracy and electronically assisted de-confliction. Under DAMM, electronic integration provides seamless communication across the operational and tactical tiers from airborne C2 (E3 AWACS), through effector platforms, down to ground-based co-ordinators (FAC/JTAC). For rapid tasking of UAS, and for interoperability with manned platforms, under the DAMM programme MoD have extended the use of standard data links and message protocols to UAS taskings. These include Link 16/J Series messages for Operational UAS (OUAS), and Improved Data Modem (IDM) for tactical UAS. For rapid exploitation of UAS output in effector platforms (RW, FW), under the DAMM programme MoD have proposed use of the K04.17 Variable Message Format (VMF) imagery message for passing still images around the DAMM network. This message is used, both over IDM and over Link16, in support of Joint Strike Fighter (JSF). In addition to the above, in support of shared SA with networked UAS, under the DAMM programme, MoD have extended the use of route data and Plan Position Location Information (PPLI). This is achieved through an adaptation of the K05.1 VMF/IDM, J2.2 Link16 messages for passing geo-location information. For route plan messages, MoD has adopted the J16.1 J Series message send over both Link16 and IDM.

A key thrust of the UAS DAMM integration work was the investigation of the utility of direct Full Motion Video (FMV) feeds from platforms such as WK and other ROVER compatible sensors, such as Reaper and Litening targeting pods, into cockpits such as Julius Chinook RW SH. This would allow the Julius Chinook crew to task a sensor carrying platform, direct from the mission system, such as the Onboard Mission Planning System (OMPS). Such tasking could provide co-ordinated over-watch and to receive live in-cockpit FMV during critical moments of operations, such as heli-borne insertion and extraction of troops. Such a capability would significantly improving SA and therefore survivability. Evidence obtained from DAMM of the utility of in-cockpit FMV directly supports procurement decisions for such a capability in addition to de-risking implementation by addressing HMI and other integration aspects.

Refer to the Annex A in the report for further detailed information on DAMM UAS Lessons Learned.

13.10 CONCLUSIONS

The DAMM SE and flight trials provide evidence with high levels of proof for real benefits of a full suite of collaborative decision support tools across all three tiers of the networked dynamic C2-MM architecture. This work contrasting DAMM architectures and networked collaborative decision making tools has shown that as data rate, confidence and context increase/improve nodal (micro) and system (macro) C2 OODA loop activity transposes from slow serial to concurrent-NRT speeds. Consequently, kill-chain timeline, fratricide and collateral incidents should reduce, as illustrated in Figure 13-10 below.

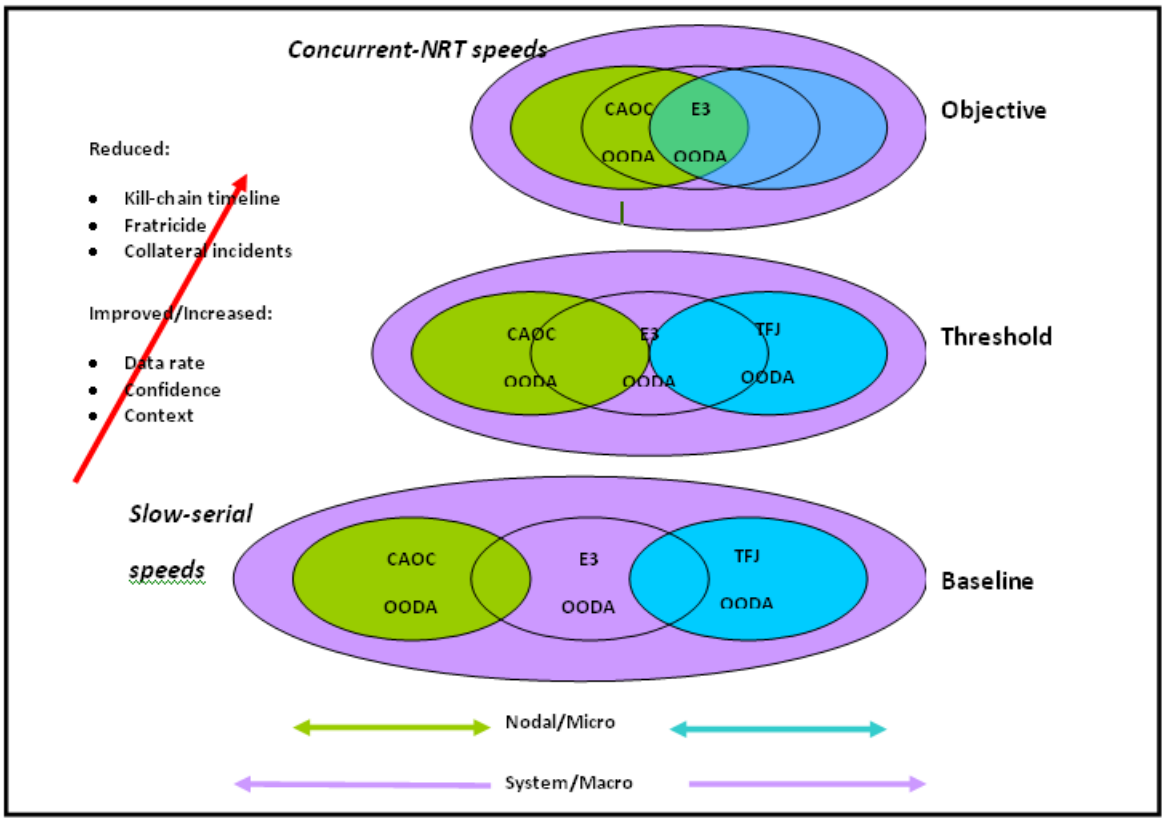


Figure 13-10: COODA Fusion.

13.11 FUTURE RESEARCH NEEDS AND PLANS IN THIS AREA

Further trials are needed to examine the effects of highly networked C2-MM architectures and MC positions on crew decision making with increasing capability provided by UAS. Work is needed to identify emerging CONOPS and architectures associated with highly networked and distributed mission systems involving manned aircraft and UAS. User requirements need to be identified and validated for tools to improve dynamic mission efficiency and adaptability and to enable improved tactical mission battle space integration, across capabilities. In particular, work is needed to focus on proactive decision support tools in support of improved anticipatory decision making. We need to improve understanding of the effects on mission command flow and locus of critical mission decision making, such as the balance of centralized versus distributed decision making. Changes in decision making strategies are likely towards more decentralized, distributed decision making afforded by networked collaborative decision support tools.

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13.13 REFERENCES

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