Chapter 2 – MILITARY RELEVANCE

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2.1 PART I – MILITARY RELEVANCE OF HUMAN FACTORS OF UMV SYSTEMS

2.1.1 Introduction

> *"Now it is clear the military does not have enough unmanned vehicles. We are entering an era in which unmanned vehicles of all kind will take on greater importance – in space, on land, in the air and at sea."*
>
> President George W Bush, address to the Citadel, December 2001.

Unmanned Military Vehicles (UMVs) are enablers of military capability with clear endorsement at the highest level. Many NATO Nations have active programmes to develop and integrate UMV systems into the front line military force mix. UMVs are most commonly characterised as dealing well with 3D tasks – dull, dirty and dangerous. They are used extensively in intelligence, surveillance and reconnaissance (ISR) roles, affording persistence in the provision of critical information, without risking lives. Increasingly, they are being considered for combat and support roles. Modern warfare needs military capability to respond to the threat of conventional hostile force and to the challenges of asymmetric conflicts, where political and military success relies on effects-based targeting and operations. In the age of Network Centric Warfare (NCW), ISR information supplied by UMV systems can be a key combat multiplier in the hands of a commander [1]. Automation technology and computer-based information processing are increasingly important for balancing affordability, capability and achievability with increasing pressures on scarce, skilled human resources. Important questions remain about what realistic effects can be expected to be achieved by UMVs in the uncertain, ambiguous and non-linear battle-space of the future, including how international law will interpret robotic warfare in the future [2,3]. However, the main consideration of this report is not so much the military relevance of UMVs, since this seems mostly self evident. Rather, the key issue is to establish why *human factors* (HF) are important military relevant issues with "unmanned" technologies. Since UMV technologies are expected to actually reduce human involvement in some tasks, it is not self evident why HF issues should warrant raised attention. Thus, the reasons for raising HF concerns are in need of review. In this report, when referencing UMVs, the term "uninhabited" will be substituted for "unmanned" where appropriate, in recognition of the role of both women and men equally in serving our armed forces.

2.1.1.1 References

[1] Curran, M. (2005). UAVs: A Critical Multiplier for Current and Future Forces. RUSI Defence Systems, Summer 2005. pp. 64-66. London, Royal United Services Institute.

[2] Burridge, B. (2005). Post-modern warfighting with unmanned vehicle systems: Esoteric chimera or essential capability. RUSI Journal, October 2005, 150 (5). London, Royal United Services Institute.

[3] Kennett, P.D. (2005). Autonomous Killing Machines – The Technical, Legal and Moral Implications. Defence Research Paper, Advanced Command and Staff Course No 8, September 04 – July 05, Joint Services Command and Staff College, March 2005.

2.1.2 Human Factors

2.1.2.1 User Requirements

UMVs are valued variously as force-multipliers, as augmenters of the force, and as adding a new component to the military force mix – but ultimately, UMVs are tools for human use. Human effectiveness is the key to all military capability. UMVs are enablers of human effectiveness and military capability. Human involvement in UMV systems is of paramount importance. HF issues need to be in the sharpest focus to mitigate the unacceptable risks of de-humanisation of decision-making in warfare.

Air Chief Marshall Sir Brian Burridge believes that in order to appreciate the capability of UAVs, we need to appreciate their limitations and benefits, but that understanding of the human dimension is the most important of all – knowing how to use them, task them and to integrate them [1]. Use of UMVs is generally justified on grounds of capability, affordability and safety. UMVs can make certain tasks safer by reducing human involvement and risk to life, allowing the possibility of human resources being re-deployed more efficiently and effectively. This produces complex changes in the balance and priority of HF issues for UMV systems. Paradoxically, for many aspects of UMV system engineering and operation, the proper consideration of HF has even greater military relevance. Human involvement remains essential throughout the UMV system life cycle, including UMV operations. As a discipline, HF provides the tools for understanding and ensuring the correct human involvement in the UMV system life cycle. Obviously, UMV habitability is not a concern. However, vehicle maintenance is still needed. Vehicle control and safety becomes a complex issue, especially when mixing UMVs with manned vehicles and "dismounted" forces. Increasing levels of UMV autonomy are expected to reduce the need for human intervention in operations. However, UMVs are not a substitute for human involvement in the battle-space. Crucially, human control of UMVs is axiomatic for military relevance (for a detailed argument for the axiomatic requirement for human control, see Chapter 2, Part II). Consideration of the technological viability of autonomous systems, and the legal constraints, suggests that a "human-in-the-loop" system will be the most valuable and therefore the most likely mode of operation to provide the required supervision and discrimination [2].

2.1.2.1.1 Battle-Space Connectivity

In warfare, the problems and outcomes are complex, dynamic, uncertain and risky, and the application of critical judgement and decision making is crucial to successful conflict resolution. Context sensitivity is important for assessing the quality of military decision making [3]. Humans encode context naturally and handle decision making adaptively with incomplete, partial and uncertain information. This provides decision making capability not easily matched by artificial intelligence (AI) in computers. However, to exercise good military judgement, humans need to feel the texture and "granularity of the battle-space" [1]. UMV operators removed from the immediate context of use, risk losing "emotional connectivity of the battle-space", operator context sensitivity and system adaptiveness. For autonomous UMV operations, the detailed level of operator supervision required is likely to be dependent on the individual mission context and the Rules of Engagement (RoE). This can be difficult or impossible to anticipate fully in advance. As a minimum, the operator needs to be able to discriminate between what is a valid military target and what is not.

2.1.2.1.2 Human in Control

Technological limitations, legal and moral constraints, and most effective human involvement, suggest that some form of human-in-the-loop control always will be required. Currently, with manned vehicles, the human operator provides the flexibility to adapt to constraints on functioning arising from system design, creates on-line tolerance of variability and uncertainty in the external environment, and offers adaptation to changing

dynamic mission context. The requirements for human-in-the-loop control of UMV operations, either remote or reach-back, can be considered as occurring at a number of levels depending on the level of automation, e.g., tasks, functions, tactical and strategic mission goals. Classes of control can be characterised as either manual, semi-automatic, and fully autonomous, with and without human supervisory control. Generally, automation best serves human purposes by enabling higher levels of human control, i.e., automate routine 3D tasks and support human supervisory control at tactical and strategic levels. The challenge is to determine the precise level of supervision required, and to identify the detailed user requirements and HF engineering solutions, for efficient and effective supervisory control.

In highly autonomous operations, communications permitting, humans can retain high level supervisory control through setting and monitoring of tasks and goals, and through authorisation of safety critical actions and use of lethal force. However, experience of automation supervision elsewhere, in particular in the process control industry and with flight deck automation has shown that reliable and robust human supervisory control is inherently difficult to achieve. Dependence on human supervisory control is risky for safety critical events and tasks. Limitations on cognition (perception, learning, memory and reasoning) mean that it is inherently difficult for humans to perform supervisory control in a consistent and reliable manner, particularly during sustained operations requiring vigilance and unpredictably intermittent high levels of attentional engagement. Ultimately, there is a risk that the over-use of automation may reduce human authority, responsibility and competency. Crucially, over-use of automation risks de-skilling the user in the important cognitive domain, reducing the essential human capability for exercising critical judgement and decision making in the appropriate use of lethal force. Finally, over-use of automation implies the risk that the human supervisor is placed 'out-of-the loop' so that he lacks actual process state knowledge (so-called peripherisation effect).

Supervisory control requires robust and reliable communications with the battle-space. The realities of military communications present a real dilemma for the supervisory control paradigm. In practice, communications technology limitations (e.g., line-of-sight and bandwidth restrictions, information quality, latency) and communications breakdown (e.g., hostile interference, electronic countermeasures) can limit feedback on mission performance and prevent real-time mission intervention during remote control operations. This may necessitate detailed mission planning, including contingencies for restricted autonomous operations when human supervision and authorisation is denied.

2.1.2.1.3 Authority and Responsibility

Human involvement is required in military operations to direct and plan the use of military capability, and to ensure lawfully correct use of lethal force. This is achieved through the application of human command authority, responsibility and accountability, and competency. With autonomous UMVs, some of that responsibility is delegated to increasingly competent computer controlled machines, but the authority and accountability for the delegation ultimately remains with humans. Ensuring the correct human involvement in UMV operations provides issues for Command and Control (C2), concept of operations (CONOPS), ROE and for the specific information display and control requirements in the context of use, i.e., ISR, combat, or support roles. For military relevance, UMV autonomy concepts must be integrated with the C2 requirements of both national and international C2 infrastructures (joint and coalition operations). C2 is rooted in human authority, responsibility and accountability, will, leadership and competency in judgement and decision making [4,5]. The potential for fully autonomous UMV operations presents significant challenges for concepts and principles of military C2. UMV control requirements need to be integrated with C2 frameworks and architectures (information flows, decision nodes, dynamic interactions), chains of command and CONOPS. This is to ensure leadership and the correct delegation of human authority, responsibility and accountability, and the necessary dynamic human interactions, with appropriate levels of trust.

2.1.2.1.4 Comprehension of Meaning

UMVs are used extensively to gather information in ISR roles for human interpretation. ISR information is inherently incomplete and uncertain. Fundamentally, computer-based information processing systems are limited in that they can not comprehend the meaning of information in human cognitive terms, e.g., apply knowledge, understand, feel truth, appreciate implications, judge consequences. Critical military judgement is needed to interpret the meaning of ISR information. Crucially, UMVs can not appreciate the effects of use of lethal force. An "emotional connectivity" is needed to appreciate the "moral value of killing and the value of human life" [2]. Critical military judgement is needed for decisions on use of lethal force. Failure to ensure proper human involvement risks rendering UMVs as unusable tools for military purposes.

2.1.2.2 Integration of Human and Automation Requirements

As a speciality, HF is traditionally concerned with the study of the man-machine interface. This also includes consideration of the equipment, the physical environment, the tasks and the individuals who do the work. Humans are involved throughout the UMV life cycle, from conceptualisation, specification, design and development, through command, control, operation and maintenance, to decommissioning. The term Human Systems Integration (HSI) is increasingly used in NATO nations to cover the broad scope of human considerations needed from a human-centred approach to systems engineering (or in a system-of-systems approach). The following definition of HSI has been agreed by NATO NSA Aircrew Integration Panel for addition to AAP-45 (NATO Glossary of Aircraft – Aircrew Integration (AI) Specialist Terminology and Abbreviations): *"The technical process of integrating the interdependent elements of Human Factors Engineering, Manpower, Personnel, Training, System Safety, Health Hazards, Survivability, and Habitability into the system acquisition process to ensure the safe and effective operability and supportability with minimised Life Cycle Cost (LCC)".* UMVs change the challenges of system safety, health hazards, survivability and habitability, reducing risks compared with manned vehicles, particularly for remote "reach-back" operations. Otherwise the HSI domains of HF Engineering, Manpower, Personnel, Training, remain as ever highly relevant for the UMV system life cycle. Notwithstanding, achieving the correct human–automation integration is a key HSI challenge for UMVs, with significant implications for HF Engineering, Manpower, Personnel and Training.

2.1.2.2.1 Manpower

Generally, UMVs are expected to augment the force and to create potential savings in human resources, manning levels and training. However, Air Chief Marshall Sir Brian Burridge, Commander in Chief, Strike, of the Royal Air Force (RAF) describes how the current manpower burden of remotely piloted operations is significant, and should not be underestimated [1]. The Air Chief Marshall reports that as part of the Predator Task Force at Nellis Air Force Base, the RAF mans a single Predator A Orbit in support of the coalition intelligence, surveillance and reconnaissance effort. This RAF unit, 115 Flight, totals 44 RAF personnel. He explains that a Predator A can orbit for 20 hours and requires 2 crew who operate for 8 hours each, totalling 6 crew for a single Predator. In addition, the operation involves analysts, data link managers, engineers in the deployed location, and the crews required to launch and to recover the UAV in theatre. This corresponds to a considerable manpower intensive effort, in stark contrast with the current aspiration of UAVs to reduce the manpower burden. In the future, UMVs may be expected to operate with increased levels of autonomy, with concomitant reductions in human involvement in platform control. Estimates of savings require comparisons with manned aircraft operations providing the same level of persistence – but on the evidence from Predator A operations, we should be careful not to underestimate the human resources requirements of UMV operations.

Esker [6] describes how the Global Hawk High Altitude Endurance UAV system, with relatively higher levels of autonomous functioning compared with Predator, has ground control facilities comprising two elements, the Launch and Recovery Element (LRE) and the Mission Control Element (MCE). The LRE accommodates two persons and is responsible for pre-flight and post-flight ground operations and the takeoff and landing phases of flight. The MCE accommodates four persons and is responsible for the mission portion of the flight, when the vehicle is at cruise altitude.

Currently, it is a priority in many NATO Nations UAV research programmes to reduce the manpower burden by reducing the ratio of operators to vehicles for flight and mission control. A common aim is to increase operator effectiveness by enabling a single operator to control multiple UAVs simultaneously (typically up to four) by introducing increased levels of automation, operator decision aiding and advanced human-computer interfaces (HCI).

2.1.2.2.2 Personnel and Training

Air Chief Marshall Sir Brian Burridge considers that softer human issues associated with operator selection and training need to be addressed urgently, ahead of some of the technological issues [1]. Predator is remotely operated by a pilot and a sensor operator. Other UAVs use a computer operator. The Air Chief Marshall expresses concern that without proper training, operators "could be faced with the very real possibility of unwrapping one of these systems for the first time on operations". Integration and interaction with civilian airspace constraints is a key training issue. He emphasises the importance of previous military experience gained in operations. The experience of operating manned platforms enables them to interact with other units and to operate safely within airspace. He notes that they understand the needs of other units through this shared connection. Solutions may need to be found in the selection of personnel with appropriate operational experience, and in creating an appropriate work context for proper operator task engagement through a combination of HF engineering, HCI and training in RoE and effects appreciation.

In the future, the possibility of increasingly autonomous UMVs can be expected to place greater cognitive demands on the operator, with little or no manual control required. Basic military skills and knowledge will continue to be important, such as airmanship and seamanship. The role of psychomotor abilities will become diminished. Performance of tasks that are likely to be required include:

- Managing and controlling multiple UMV missions;
- Co-ordination and de-confliction of multiple UMV assets;
- Interpreting and integrating command strategic intent, RoE and mission control requirements;
- Recognizing and dealing with degraded system functionality;
- Regaining SA after loss of UMV data links;
- Interpreting displays containing multiple UMV perspectives;
- Shift of system control to other team members or control stations; and
- Team-working and interpersonal interaction.

The emphasis will be on the UMV operator as a mission manager, on multi-task management and performance, on judgement and decision-making skills, and on the cognitive ability to integrate and interpret dynamic, complex data, in order to make rapid and effective decisions. For a detailed discussion of manpower, skills and training requirements, see Chapter 4.

2.1.2.2.3 HF Engineering

From a system-of-systems point of view, the term "unmanned" is potentially misleading. It is most certainly inappropriate from an HF engineering perspective. It suggests an absence, or a reduction, in human involvement, and consequently a lack of, or a lessening, in human system issues. This is particularly unfortunate since the opposite is probably nearer the truth. UMVs remove humans from the vehicle (or platform) and the hazardous operating environment. However, UMVs do not remove humans from the system of use. At the present time, with human-in-the-loop control, advances in autonomous vehicle technologies are worthless without an effective and efficient operator remote control/display interface [7].

Generally, separating operators from the context of use risks disconnection from the battle-space, reduced SA, and creates difficulty in decision making and in maintaining the level of control and feedback on the effects of use. Rather than reducing the human system issues, increasing remoteness may risk reducing the operator's capability to provide effective task engagement, situation appreciation and timely interventions. Increased levels of autonomy may reduce some of the human-in-the-loop workload, but autonomy risks the effects of disconnection identified above. Research is needed both on AI techniques for autonomy and on HF of supervisory control. For a detailed discussion of relevant AI techniques, see Chapter 5. The risk of disconnection raises the importance of HF engineering for enabling supervisory control and for exploiting the potential mitigations afforded by advanced HCI design, augmented cognition technologies, SA tools and operator decision support aids. HCI style guide information is available for interoperability between UAV Control Stations (UCS) in NATO STANAG 4586 [8]. HCI is a rapidly advancing field and research is needed to provide properly validated advanced HCI solutions for future improved UCS. For a detailed discussion of advanced UMV operator interfaces control/display requirements, see Chapter 6.

It has been suggested that UMVs may shift the balance of responsibility and accountability for UMV behaviours and effects from users' decisions during systems operation towards engineers' decisions during system design. The development of this argument could depend on technological developments affecting the future possibility of machines that never make mistakes, the levels of automation employed, and the methods of supervisory control of operations and effects. International humanitarian law on military use of lethal force in conflict seems likely to keep responsibility and accountability firmly with the user/commander. So, with increasing levels of autonomy, the need for system transparency and SA could grow. User involvement in systems requirement specification will become increasingly important to ensure that critical military judgement can be properly exercised in the context of use. This could necessitate real time user/commander control of the level of automation (i.e., adjustable, variable levels of automation), in addition to supervisory control of the specific UMV operations and effects.

2.1.2.2.4 Human-Computer Decision Partnership

Reising [9] describes how in the future, rather than coping with unreliable human supervisory control, or simply removing the operator from the control loop entirely, the paradigm for operator control will need to progress to one based on human-computer co-operation, as implemented in advanced pilot assistance systems. Reising predicts that future UMVs will contain associate systems that will enable the UMV operator and the associate to form a team of two crewmembers – one human and one electronic. Onken [10] calls this partnership *cognitive co-operation*. Ensuring the success of this necessary partnership presents significant challenges for HF of UMV systems. Research has shown how real-time HF engineering of variable levels of automation or adjustable levels of autonomy are important for controlling multiple autonomous UMVs, and provide the key to developing an adaptive human-computer decision partnership [11,12,13]. Alternative theoretical frameworks for UMV systems are discussed in Chapter 3. Levels of automation are discussed in detail in Chapter 7.

Ideally, a flexible approach is needed that allows a variable level of human intervention and autonomy, with the need for "drill-down" judged in real-time. For efficient and effective mission supervision and discrimination, the operator/supervisor needs to be able to bring added value to the understanding of the situation [14]. To add value, he/she will need to be able to use knowledge (e.g., RoE, situation awareness, tactics) and to take into account additional contextual decision information not available to the UMV information processing system. Otherwise, the level of supervision may be uncritical and lack any real operator decision input, with the resultant legal implications. One example to avoid would be authorising target prosecution for autonomous UMVs based only on pre-set automatic target recognition (ATR) criteria without independent operator verification of the target context RoE. To mitigate this, the C2 system and UCS need to provide a rich operating picture for mission assessment and appropriate mission performance critiquing tools.

2.1.2.3 References

[1] Burridge, B. (2005). Post-modern warfighting with unmanned vehicle systems: Esoteric chimera or essential capability. RUSI Journal, October 2005, 150 (5). London, Royal United Services Institute.

[2] Kennett, P.D. (2005). Autonomous Killing Machines – The Technical, Legal and Moral Implications. Defence Research Paper, Advanced Command and Staff Course No 8, September 04 – July 05, Joint Services Command and Staff College, March 2005.

[3] Bolia, R.S., Nelson, W.T., Vidulich, M.A. and Taylor, R.M. (2004). From chess to chancellorsville: Measuring decision quality in military commanders. In: D.A. Vincenzi, Mouloua, M. and Hancock, P.A. (Eds), Human Performance, Situation Awareness and Automation: Current Research and Trends, HPSAA II, Volume I. pp. 269-273. Mawhah, NJ: Lawrence Erlbaum.

[4] Pigeau, R.A. and McCann, C. (2000). Re-defining Command and Control. In: C. McCann and R.A. Pigeau (Eds.), The Human in Command: Exploring the Modern Military Experience (pp. 163-184). New York: Kluwer Academic/Plenum Publishers.

[5] Pigeau, R.A. and McCann, C. (2002). Re-conceptualising Command and Control. Canadian Military Journal, 3(1), 53-63.

[6] Esker, M. (2004). Projection of Workload in Multiple UAV Control. In: Uninhabited Military Vehicles (UMVs) – Human Factors of Augmenting the Force. RTO-MP-111, RWS-010-OKN2. Proceedings of the NATO RTO Human Factors and Medical Panel Workshop held in Leiden, The Netherlands, 10-13 June 2003. NATO RTO: Neuilly-sur-Seine Cedex. March 2004.

[7] Taylor, R.M. (2003). Capability, Cognition and Autonomy. In: The Role of Humans in Intelligent and Automated Systems, MP-088, Keynote Address KN-03. Proceedings of the NATO RTO Human Factors and Medicine Panel Symposium, HFM-084/SY-009, held in Warsaw, Poland, 7-9 October 2002. NATO RTO: Neuilly-sur-Seine Cedex.

[8] NATO, (2001). STANAG 4586 Standard Interfaces of UAV Control System (UCS) for NATO UAV Interoperability, NATO Military Agency for Standardisation, Draft Version 2.4 September 2001.

[9] Reising, J. (2003). Uninhabited Military Vehicles: What is the Role of the Operators? In: The Role of Humans in Intelligent and Automated Systems, MP-088, Keynote Address KN-04. Proceedings of the NATO RTO Human Factors and Medicine Panel Symposium, HFM-084/SY-009, held in Warsaw, Poland, 7-9 October 2002. NATO RTO: Neuilly-sur-Seine Cedex.

[10] Onken, R. (2003). Cognitive Co-operation for the Sake of Human-Machine Team Effectiveness. In: The Role of Humans in Intelligent and Automated Systems, MP-088, Keynote Address KN-05. Proceedings of the NATO RTO Human Factors and Medicine Panel Symposium, HFM-084/SY-009, held in Warsaw, Poland, 7-9 October 2002. NATO RTO: Neuilly-sur-Seine Cedex.

[11] White, A.D. (2002). The human-machine partnership in UCAV operations. In: Proceedings of 17th Bristol UAV Systems Conference, 10-13 April 2002.

[12] Ruff, H.A., Calhoun, G.L., Draper, M.H., Fontejon, J.V. and Guilfoos, B.J. (2004). In: D.A. Vincenzi, Mouloua, M. and Hancock, P.A. (Eds), Human Performance, Situation Awareness and Automation: Current Research and Trends, HPSAA II, Volume II, pp. 218-222. Mawhah, NJ: Lawrence Erlbaum.

[13] Frampton, R. (2005). UAV Autonomy. Distillation, The Dstl Science Journal, Issue 9, pp. 16-19.

[14] Cottrell, R.J., Dixon, D.G., Hope, T. and Taylor, R.M. (2005). Operator in the loop? Adaptive Decision Support for Military Air Missions. In: Proceedings of the 1st International Conference on Augmented Cognition, Las Vegas NV, 25-27 July 2005. New Jersey: Erlbaum.

2.1.3 Operational Benefits of UMVs

Interoperability within the force mix is a key challenge for UMVs and HF. Commodore Lambert, UK Director of Equipment Capability (Underwater Battle-space) has characterised the battle-space of today as encompassing air, land and sea domains, requiring sensor coverage and connectivity across all boundaries [1]. In this battle-space, Commodore Lambert has identified several operational advantages in military missions derived from employing UMVs in airborne, ground and underwater systems:

- Minimise or eliminate risk to personnel and expensive platforms through autonomy.
- Access, under all-conditions, to denied or unsafe areas of operations.
- Force multiplication through the ability to operate independently for extended periods, enabling manned platforms to extend their reach and focus on more complex tasks.
- Automated reconnaissance, surveillance, target acquisition, target designation, tactical oceanography, battle damage assessment, etc., through the use of miniaturised, low energy sensors/payloads.
- Secure network enabled warfare via data relay and connectivity at extended ranges between multiple vehicles.
- Mission flexibility through their ability to be deployed from a variety of host platforms.

Of the three main classes of UMVs – airborne, ground and underwater systems – uninhabited air vehicles (UAVs) and to a lesser extent, uninhabited underwater vehicles (UUVs) have attracted the wider operational interest. UAVs have probably resulted in the most significant technical activity from a human factors perspective. The following sections reflect this balance of military interest, HF issues and research activity.

2.1.3.1 Uninhabited Ground Vehicles

Uninhabited ground vehicles (UGVs) were first used by the German Army in World War II for tasks such as mine field breaching (e.g., Goliath, Borgward IV). Early UGVs have been particularly successful in support of space operations, such as the Lunar and Mars rover vehicles. The first such vehicle was the Russian Lunakhod 1 which was tele-operated on the moon in the 1970s for 11 days over a distance of 10 km. Currently,

the majority of UGVs are tele-operated line-of-sight systems, with research directed at the development of autonomous unmanned/robotic technology. Strong [2] summarises the potential use of UGVs as including the following roles:

- Mine detection and neutralisation;
- Explosive ordnance clearance and disposal;
- Reconnaissance, surveillance and target acquisition;
- Operations in contaminated areas and contamination assessment (e.g., detection and analysis of chemical, nuclear and biological assets);
- Urban warfare operations in confined spaces;
- Fire fighting;
- Logistics (e.g., delivery to the battlefield of munitions, fuel, parts, food and water);
- Casualty recovery;
- Security and patrol;
- Deployment of weapons or obscurants;
- Deployment as a mobile communications link;
- Deployment as a mobile power supply; and
- Deployment as a decoy target.

Current UGVs have important military roles for reconnaissance and surveillance in support of urban operations, particularly for working in confined, restricted and dangerous environments, such as fire-fighting (e.g., Carlos), breaching (e.g., Caterpillar D7), searching underground in caves, culverts, drains and man holes and searching collapsed buildings, i.e., areas not subject to aerial observation (e.g. PackBots, Man Portable Robotic System). Generally, for military purposes, UGVs experience major challenges to mobility and manoeuvrability due to sensing and avoidance difficulties with unexpected ground obstacles and crevices, and due to terrains (rugged going, gradients, instability, terrain, grip and ground clearance; building sites and interiors; smooth surfaces; cluttered environments; low tide, streams, puddles, mud). Research has shown that failure rates in urban terrain are relatively high with a mean-time between failures on average of between 6 – 20 hours. Because of the relatively restricted nature of UGV tasks, they are relatively unsophisticated in terms of requirements for levels of automation and autonomous functioning. UGVs are mostly operated by remote control, requiring robust, compact and portable operator control stations, with relatively simple control and display interfaces.

Remotely controlled UGVs have a significant current role as tools for detecting hazardous and dangerous materials (chemical, biological, radiation, nuclear – CBRN), and in particular for counter-mine, Explosive Ordnance Devices (EOD) and Improvised Explosive Devices (IED) tasks, e.g., RONS – Remote Ordnance Neutralisation System; ARTS-All purpose Robotic Transportation System; M60 Panther (Common Robotic System), a tele-operated turret-less M1 tank equipped with rollers for mine clearance; Mini Flail for anti-personnel mines and booby traps; Wheelbarrow tele-operated tracked robotic bomb disposal vehicle; Cyclops, and Buckeye Miniature Remotely Operated Vehicle (MROV) for work in urban areas and confined spaces, such as aircraft, buses and trains; Talon, a remotely operated vehicle-based telescopic manipulator, acts as both a reconnaissance vehicle and a weapon and camera platform. The current version of Talon is a semi-autonomous unmanned vehicle capable of firing rifles, machine guns, grenade launchers and rockets.

Control of UGVs for EOD/IED operations involves the following HF challenges:

- Systems operations difficulties – power supply management, ambient lighting problems, visual issues, control feedback.
- System performance issues – lag and gain in control response critical for EOD/IED work, stopping distance, proportional gain controls, mode types, simultaneous control of multiple parameters.
- Operating from moving platforms – motion sickness, orientation.

In addition, the EOD/IED operational environment involves complex problem solving and high levels of operator situational awareness. This requires high levels of operator and team skills and experience. Training of EOD/IED operators is an important area for HF work. This summary of EOD/IED HF requirements is based on the UGV briefing by Paul Burns, SOE Academy and Nicki Heath, Symbiotics, provided to HFM-018 at the meeting in Bath, UK on 24 May 2005.

UGVs are currently used for payload delivery (e.g., R-Gator, Military Robotic Gator), such as fire brigade, medical supplies, hostage scenarios and electronic counter measures (ECM) equipments. Digney [3] provides a review of research at DRDC-Suffield on UGVs including the following:

- Unmanned Scout Vehicle – Tele-operated, for reconnaissance operations;
- Caterpillar D7 – Both telematic and on-board human operator, for earth working; and
- Improved Landmine Detection Programme (ILDP) – Telematic control for landmine detection.

Digney summarises the military benefits and issues of UGVs as follows:

- Removal of soldiers from hazardous and hostile environments.
- Robot must win – whatever telematic, shared control or autonomous system is fielded, the robot must prevail in competitive conflict.
- Hiding complexity from operator control – provide autonomous control of low level functions, while human controllers supply high level and intuitive directives.
- Amplified use of manpower – field more vehicles per human controller, and deploy freed personnel to other vital roles.
- Persistent attention – use shared control and persistent search for detection of scene changes and enlist human assistance in change classification, to mitigate fatigue and inattentiveness.
- Lethal force control – automatic control of lethal force is not permitted by current ethical considerations. Whenever lethal force is to be applied from an UMV, a human operator must be in direct control.
- Life critical operations – infra-red image classification on the IDLP mine detection vehicle is currently done by a human because automatic classification performance risks machine classification error and endangers human lives.
- Sacrificial vehicles – unmanned vehicles losses are more acceptable.
- Communications silence and jamming – Urban areas exacerbate problems with communications links assurance, jamming of communications is common, communications give positions and intent away, and should be kept to a minimum and performed through undetectable means.

- Acceptable path to higher autonomy – use incremental route levels of autonomy, supported by incremental verification, a demonstrable safe path, with progress and reliability observed by the operator.

Future UGVs are envisioned for more complex and hazardous tasks, such as casualty evacuation (REV-Robot Evacuation Vehicle, REX-Robotic Extraction Vehicle), with more challenging technical requirements, complex safety issues, and potentially high levels of automation. Future UGVs are planned with improved capability for remote-controlled, semi-autonomous and autonomous operation and improved mobility, flexibility and multi-functionality. Enabling technologies include ground positioning systems, autonomous navigation, automatic collision avoidance, perception and navigation sensors, intricate and precise positioning, and artificial intelligence techniques (e.g., hierarchical learning, adaptive control, neural networks). The US Army's planned Future Combat System (FCS) is largely built on UMV concepts (manned vehicles plus UAVs, unattended munitions and UGVs). FCS UGVs comprise the Armed Robotic Vehicle (ARV) with assault and RSTA (Reconnaissance, Surveillance, and Target Acquisition) variants, and the Multi-purpose Utility/Logistics Equipment (MULE) for countermine and transport.

Looking further to the future, the US Joint Forces Command's Project Alpha includes "Unmanned Effects: Taking Humans Out of the Loop". This seeks to explore the idea of that autonomous, networked and integrated robots may be the dominant fighting force by the year 2025 (http://www.jfcom.mil/newslink/storyarchive/2003/pa072903.htm accessed 12/12/2005). In 2003, DARPA's "Centibots" project on distributed robotics looked at co-ordinated deployment of groups of 25 – 50 robots in advanced surveillance teams for urban missions, including area surveying, sharing a distributed map and intruder detection (http://www.ai.sri.com/centibots accessed 20/11/2005). Several advanced research programmes are using biomimetics, the engineering of a process or system that mimics biology, to investigate behaviours in robots that emulate animals such as self-healing and swarming [2].

2.1.3.2 Uninhabited Underwater Vehicles

Uninhabited underwater vehicles (UUVs) have been deployed by NATO Nations in a variety of civilian and military roles. Both US and UK have active research and development programmes. In the military underwater domain, more than others, research has been characterised by a desire for a direct route to behaviourally simple, but fully autonomous, UUVs. This seems mostly due to the military importance of the littoral zone with very shallow water (VSW) and surf-zone (SZ) operations, and the associated problems of difficult underwater acoustic communications (AComms).

Carver [4] has identified a variety of roles for UUVs in the underwater battle-space derived from operational analysis, surveys of likely users and initial concept of operations studies:

- Mine Countermeasures (MCM);
- Environmental Data Gathering (EDG);
- Rapid Environmental Assessment (REA);
- Above and Below Water Intelligence Gathering;
- Anti Submarine Warfare (ASW) – Trainer;
- Expendable Sensor Deployment;
- Mobile Signature Range;

- ASW Bi-Static Sonar Operations; and
- ASW Track and Trail.

Commercially available Remotely Operated Vehicles (ROVs) are in relative abundance for deepwater operations. Underwater ROVs tend to be tethered to a mother ship via an umbilical cord, supplying power and command and communications links. There is considerable experience using underwater ROVs in the oil industry for offshore support. Specific examples include the Maridan 600 ROV UUV from Denmark, and the Hugin ROV UUV out of Norway. In addition, UUVs have been used in varied environments for scientific work. Academic ROVs include the Woods Whole Oceanographic Institute's REMUS (Remote Environmental Monitoring UnitS), Florida Atlantic University's Morpheus, Massachusetts Institute of Technology's Odyssey and Cetus II, and Southampton Oceanography Centre's AutoSub UUV. In the UK, Tiltman [5] reports that the combined experience of industry and academia is currently being used to reduce the risk to UUV procurement for the next 10 years under the UK MOD Battlespace Access UUV (BAUUV) programme, 2003 – 2006.

Tiltman [5] describes how the UK MARLIN 1995 – 2003 research and development programme was based on torpedo technology from SPEARFISH and MK24's. MARLIN was designed for submarine launch and recovery, with a unique top speed of 15 kts. Recovery proved particularly difficult and requirements for submarine operations have subsequently waned. He reports that the Royal Navy currently has two derivative REMUS UUVs in active service, surveying areas in and around ports, harbours, ship lanes and landing areas. The US Navy is developing LMRS (Long Term Mine Reconnaissance System), a mine hunting UUV. These free swimming UUVs tend to be very small, of limited endurance, with a single specific task, such as inspection of underwater objects. Tiltman reports that joint US/UK GAMBIT programme is developing mine-warfare UUV sensors. GAMBIT uses a 21" UUV built by Bluefin Robotics to investigate Synthetic Aperture Sonar (SAS), mission autonomy and navigation systems. He believes that SAS holds the possibility of allowing a UUV to survey a boat lane in one sweep at 4 kts. This will significantly change mine warfare tactics, affect the whole amphibious operation, and significantly reduce the risk to military personnel.

Posey [6] argues that MCM is a key role for UUVs, e.g., RAUVER, REMUS. The sea mine remains a powerful and cost effective asymmetric threat of significant concern to the maritime forces. Posey believes that current dedicated MCM capabilities will not satisfy the requirements of the future battlespace. He reports that this is because current MCM capabilities are limited by lengthy timelines for surface assets to arrive in theatre, inadequate integration of assets, minimal reconnaissance means, and operational pauses created by the slow, deliberate nature of MCM operations.

Waters and Taylor [7] report that the US Navy envisage the littoral zone to be the most important for UUV operations, from MCM prior to a naval assault, through coastal and channel mapping via sonar, to deploying sonars near enemy naval installations to track asset movement and even kill them with torpedoes. MCM and Explosives Ordnance Disposal are key operational tasks for UUVs in VSW/SZ operations. Blackburn et al. [8] report that a VSW MCM detachment comprises 70 personnel: 40 are in operations, mostly diver qualified, 18 go into the water, 21 service and control dolphins, and 6 will operate UUVs. The dolphins locate the mines using endogenous sonar, then drop pingers to tag locations. For SZ operations, brute force neutralisation is used by laying down a blanket of charges for in-stride breaching.

Blackburn et al. [8] note that the closer the UUV is driven to the beach, the greater the sensing, navigation, communications and control problems become. With ROV, in both VSW/SZ and deep water operations, there is the possibility of increased difficulty of task execution with tele-operated ROV control from a distance. This is particularly problematic if information is changing quickly, or restricted, as it often is in the complex terrestrial environment and near beach underwater environment.

A major factor governing UUV operations is the availability of power. Strong currents and water turbulence can make station keeping difficult to achieve and drain power. Walters and Taylor [7] describe how retaining and managing power is an important UUV task, and a strong candidate for automation. The power source will also have to be wholly internal to the vehicle. This is currently based on batteries, although it is likely that fuel cells will replace these as the technology improves. Even the latter will only yield a useful energy output of about 400Wh per kg, with the potential to (possibly) double this figure within the next 5 years. With current UUVs, such as the USS Manta, requiring up to 50 kW for propulsion alone, plus several kW more for sensor operation (e.g., sonar), the size of the problem of supplying sufficient power to allow the performance of any kind of mission becomes apparent. The addressing of this power management problem, which is usually denoted by HOTEL, boils down to answering the question "can I do the mission and return to my recovery point on my power reserves?" This base-lining of the projected energy consumption for the whole mission, continually updated during the mission, underpins every other assessment and decision made during the mission.

In wider concepts, UUV missions may last for days. Alternatives include large UUVs carrying a variety of sensors and deploying sensor arrays, and smaller vehicles firing torpedoes [4]. This plethora of UUV roles leads to the concept of adopting a modular design, where different operational modules can be fitted, so providing 'swing roles' from a baseline vehicle. Carver notes that a common thread emerges. To achieve the desired range and endurance, and to deliver the required capability, UUVs are becoming larger, embodying more autonomy and developing into complex 'systems of systems.' As with current UAVs, UUVs will soon fire weapons on command, requiring reliable secure underwater communications systems. Further into the future, the ultimate 'leap of faith' will be to permit weapons to be released autonomously.

Looking into the future, iRobot have a DART biomimetic programme for small, autonomous UUVs that emulate the efficiency, acceleration and manoeuvrability of fish. Also, they have proposed ALUV (Ariel Autonomous Legged Underwater Vehicle), a crab-like robot, for mine and obstacle neutralisation. ALUV would secure itself to the mine and await a detonation signal, or deposit an explosive.

2.1.3.3 Uninhabited Air Vehicles

2.1.3.3.1 Benefits of UAVs

In 2004, NATO Industrial Advisory Group (NIAG) Study Group 75 reported an overview of status of UAV technology from a NATO industry perspective [9]. In general, it is believed that the ability of UAVs to perform their missions with autonomous capabilities will be a major step towards achieving flexible, efficient and interoperable military (including combat) operations. Broadly, the advantages of UAVs are believed to include the following:

- Reduced risk to humans;
- Optimised operator performance;
- Reduced training requirements;
- Improved contingency management;
- Reduced data link demands; and
- Increased operational flexibility.

Air Chief Marshall Burridge [10] concisely summarises the strengths and challenges of UAVs as follows:

Strengths

- Dealing well with 3D tasks – dull, dirty and dangerous;
- Potential response at a number of levels, ranging from resolving tactical firepower problems to providing commander's strategic critical information requirements;
- Ease of re-tasking;
- Increase stand-off ranges for kinetic, and non-kinetic or cognitive attack; and
- Persistence.

Challenges

- Interoperability of systems;
- Vulnerability;
- Limited capacity to address a wide surveillance;
- Insatiable demand for bandwidth; and
- Inability to deal with ambiguity in the same way as manned aircraft.

2.1.3.3.2 Classes of UAV

A parallel activity has been conducted under the NATO Systems Concepts and Integration Panel (SCI) Panel, namely NATO SCI-124 Task Group, Architecture for the Integration of Manned and Unmanned Air Vehicles. Close liaison between SCI-124 and HFM-018 was conducted principally by UK, US and GE TG members. This interaction has been particularly beneficial for HFM-018 in identifying a range of UAV assumptions. For the purposes of the present report, basic information on C2 architecture, tasks and classes of UAVs are taken directly from the Final Report of NATO SCI-124 Task Group [11].

Six classes of UAV are identified by SCI-124 with role-specific platform characteristics and control requirements. These are summarised in Table 2-1 below from the SCI-124 Final Report.

Table 2-1: Summary of UAV Classes, Roles and Control

Class	Description	Role	Control

CML-UAV	Like cruise missile
	Subsonic, reusable
	Deep penetration, low altitude, terrain following
	Independent operation or in support of manned strike aircraft
		Pre strike recce
		Post strike recce (BDA)
		Target identification
		Target verification
		Third party target illumination
			Automatic:
			• Flying
			• Pre-programmed:
			  • Flight path
			  • Sensor operation
			UCS:
			• Flight, mission
			• Update way points
			• Payload

Class	Description	Role	Control

CAL-UAV (UCAV)	Like combat aircraft
	Deep penetrating stealthy ground attack
	Examples: Joint Unmanned Aerial Combat System (J-UCAS) demonstrators:
	• Boeing X-45
	• Northrop Grumman X-47 Pegasus
		Strike
		SEAD
		DEAD
		Recce
		Surveillance
			Automatic:
			• Flying
			• Pre-programmed with human-in-the-loop, or autonomous:
			  • Target acquisition
			  • Target verification
			  • Weapon release
			UCS (+ CAOC, AEWC):
			• Flight, mission
			• Update way points
			• Payload

HALE-UAV	High altitude, Long endurance
	Examples:
	• Global Hawk
	• General Atomics Predator B
		Stand off
		Strategic
		Over target area
		Surveillance
		Recce (IMINT, SIGINT)
		Target acquisition
		Stand-off jamming
			Automatic:
			• Flying
			• Pre-programmed:
			  • Flight path
			  • Sensor operation
			UCS:
			• Takeoff, landing
			• Flight, mission
			• Update way points
			• Payload

MALE-UAV	Medium altitude – up to 10 km
	Long endurance, Medium speed
	Examples:
	• Predator
	• Hunter
	• Heron
	• Watchkeeper
		Stand off
		Tactical
		Over target area
		Surveillance
		Recce (IMINT, SIGINT)
		Target acquisition
		Stand-off jamming
			Automatic:
			• Flying
			• Pre-programmed:
			  • Flight path
			  • Sensor operation
			UCS:
			• Takeoff, landing
			• Flight, mission
			• Update way points
			• Payload

VTOL-UAV	Future, vertical take-off and landing Forward base operations range (radius) 500 km fast (>300 km/h) low (nap-of-the-earth)	Combat search and rescue (CSAR) Casualty variant (armoured cabin) Escort protection variant: • Remotely controlled machine guns • IR-/TV-cameras	UCS: • Monitor and control flight, mission • Control/operate escort weapons

Class	Description	Role	Control
FAL-UAV	Future, like fighter aircraft Air combat Highly agile Supersonic	Air combat, highly reactive against hostile manned fighter aircraft and enemy's UAVs	Automatic: High levels of autonomy (2020): • Pre-programmed ingress and egress • Air-target acquisition • Initiation of combat flight manoeuvres • Tactical manoeuvres based on human intelligence • Weapon selection • Weapon release • Fire control UCS (+ CAOC ,AEWC): • Flight, mission • Update way points • Monitor autonomous operation • Interrupt weapon release
Mini-UAV	Small portable reusable Takeoff weight < 5 kg Range < 10 km Altitude 500 m Endurance 30 minutes. Example: Dragon Eye	Support for ground forces Beyond visible range (BVR) capability Reconnaissance Target acquisition	UCS: • One person operation • Mobile • Laptop • Hand-bag portable

2.1.3.3.3 UAV Control Stations

All the UAV classes identified are operating automatically with pre-programmed flight paths and pre-programmed payload/sensor control. The UAV operators can change the way points and the sensor control functions in the tactical UAV Control Stations (UCS) during the flight. Furthermore, the UAV and payload control can be handed over to the CAOC or other sea-, land- or air-based tactical UCSs at any time during the flight. Autonomy levels define the UAV's level of control and hence the required commands to control it. At present, UAVs need a UCS with an operator. The location of the UCS is critical for future CONOPS. The UCS location could be remote, or located in an accompanying aircraft. The functions of the UCS are summarised by SCI-124 as follows:

- C2 of air vehicle and payload (including weapons);
- Possibly (limited) processing, display and exploitation of sensor data;
- Communications with Air Control Centre (ACC); and
- Dissemination of UAV sensor data to users.

The UCS can be land, sea or air-based. UCS can control many UAVs. One UAV can be controlled (over time) by many UCS both on the ground as airborne, but never at the same time.

Currently, one UCS is needed to operate one UAV. SCI-124 believes that future UAV systems will have the ability to control several vehicles with one UCS. Control of a UAV or payload may be passed from one UCS to another. Control handover and associated operator workload issues will need to be considered in deriving the integration and C2 requirements for a manned and unmanned aircraft mix.

2.1.3.3.4 UAV Autonomous Control Levels

The DoD UAV Roadmap 2002 defines 10 levels of autonomous control (ACL). These provide a quantification of the wide range of UAVs that will affect UCS HF requirements:

- ACL 10 – Fully autonomous swarms;
- ACL 09 – Groups strategic goals;
- ACL 08 – Distributed control;
- ACL 07 – Group tactical goals;
- ACL 06 – Group tactical re-plan;
- ACL 05 – Group coordination;
- ACL 04 – Onboard route re-plan;
- ACL 03 – Adapt to failures and flight conditions;
- ACL 02 – Real time health diagnosis; and
- ACL 01 – Remotely guided.

The Predator UAV is represented as at ACL 2, Global Hawk UAV as at ACL 2.5. ACL 5 should be reached by 2010.

SCI-124 believes that a UAV must respond to commands in a timely way, similar to manned aircraft. This is achieved by the combination of operator intervention and ACL. It is assumed that by definition, at low UAV ACL, there will be much greater operator intervention, and at high ACL, only little operator intervention will be required. Implementation of this vision of increasing delegation of UAV control to automation together with a managed reduction in operator involvement per UAV presents major HF challenges.

Current UAVs have limited sense and avoid capability. SCI-124 have concluded that enhancement of current UAV sense and avoid capability will be essential in order to mix manned and unmanned aircraft in the same package. They note that future UAV systems will require sensors that detect traffic and robust automatic collision avoidance systems that are able to react in a manner similar to a manned aircraft.

2.1.3.3.5 C2/ISR UAVs

Looking to the future requirement for UAVs in the US Army, Curran [12] describes the future core capabilities for command and control (C2), as well as intelligence, surveillance and reconnaissance (ISR). He states that UAVs are becoming increasingly important in enabling ground forces "to *see first, understand first, act first,*

and then finish *decisively"*. He believes that they provide critical information without jeopardising or risking lives. He notes that as range, altitude and loiter time increase UAVs are providing "the eyes" to support line-of-sight and beyond-line-of-sight reconnaissance, fires and over-watch. As a result, Curran describes that this support enables rapid movement, target identification and engagement, and enhanced battle damage assessment, giving commanders greater understanding of the effects of their combat operations. In future, Curran believes that all classes of UAVs will have the following core capabilities:

- Networked systems-of-systems using the Future Combat System (FCS) common operating environment, common computers, software, sensors and battle command communications management.
- Embedded autonomous flight control and navigation, and safe flight protocols.
- Unprecedented reliability, maintainability and operational availability reducing the quantity of logistics support.
- Condition-based maintenance with sophisticated prognosis and diagnosis data networked into the Brigade Combat Team.
- A reusable platform durable against environmental effects.
- Power sources readily available within the BCT and compatible fuel/power cells.
- An anti-tamper capability.
- A means to sense and report a personnel and vehicle presence night and day.
- The ability to report target and platform locations.
- The capability to detect and report location and direction of threat systems acquiring, or targeting, the UAV platform.

2.1.3.3.6 Combat UAVs

Of particular significance in looking to the battlefield of the future, the Joint Unmanned Combat System (J-UCAS) is a joint effort between the Defence Advanced Research Projects Agency (DARPA), the US Air Force and the US Navy. Francis and Hirschberg [13] describe how the J-UCAS programme seeks to exploit the potential of a networked system of high performance, weapon-carrying unmanned aircraft with the ability to penetrate and persist deep within the enemy territory. J-UCAS is intended to develop the capability for unmanned aircraft to cooperatively locate and attack an integrated air defence system (IADS) without risking the lives of pilots. Francis and Hirschberg report that the high levels of autonomy planned for J-UCAS are crucial for operating world-wide, independently of degraded communications. Autonomy is needed so that degraded communications, whether caused by sunspots or jamming, must not impair the aircraft functionality or the system's ability to complete missions within the assigned rules of ROE. The example ROE given is the use of force only authorised by the human operator. According to Francis and Hirschberg, the intention is for J-UCAS to move from the current crewing norm involving multiple operators controlling a single UAV, to a new crewing paradigm with multiple aircraft being controlled by a relatively small number of operators. They state that the vision is that this will be achieved with the operators' tasking optimised for workload and mission-critical needs. J-UCAS will collaborate with other J-UCAS aircraft and additional assets to enhance overall SA and improve the speed and precision of geo-location, identification, tracking, and attack and assessment of targets. Operating at the speed and altitude of commercial air traffic, J-UCAS will have a "sense and avoid" capability to be able to operate routinely in the global air traffic management system together with an automated aerial refuelling capability. Collaboration with the UK Ministry of Defence has been established to investigate the military benefits and interoperability issues in future coalition operations through experimentation and distributed real-time simulation.

2.1.3.3.7 NATO Allied Ground Surveillance System

Currently, NATO has a requirement for an Allied Ground Surveillance (AGS) system in support of their activities. AGS is a method to support Peace Keeping and other military operations. It requires a radar system capable of simultaneous Synthetic Aperture Radar (SAR) mode and Moving Target Indicator (MTI) mode. These modes must perform at long stand-off distances and in high resolution. The system must within a large area of interest image any details with the SAR mode; in the MTI mode it must detect, track and classify moving targets. The AGS is primarily designed for military use, but also proves efficient in border control activities.

Five European countries (Germany, France, Italy, Spain, and The Netherlands) have responded to a NATO request and proposed a demonstrator, the Stand Off Surveillance and Target Acquisition System (SOSTAR) [14]. The SOSTAR demonstrator is intended to perform all the required functions of the full scale model, including the simultaneous interleaved operation of SAR and MTI, but has a small antenna size to reduce cost. The system could be used as a basis for an AGS system on UAV's and on small aircraft. The final version of SOSTAR is foreseen to have a scalable antenna and is suitable to be installed on NH-90 helicopter platforms and High Altitude Long Endurance (HALE) UAV's. The system may become available by the end of the decade. The system is set up in such a way that that it can not only fulfil NATO's requirements, but also any upcoming national requirement. Although AGS systems are still in their childhood, the first valuable experiences are there.

2.1.3.3.8 Future Autonomous UAVs

NIAG SG-75 reported the following conclusions regarding the development and operation of autonomous UAVs [10]:

- Operating future autonomous UAV systems within a Network Centric Warfare (NCW) environment will be enable the human to assume the role of system manager, rather than system operator, and that will be advantageous for a variety of missions.
- The development of autonomy for UAV systems is feasible. It will depend not just upon the development of technologies identified in this study, but also upon doctrinal and policy considerations, particularly during operations with combat UAVs.
- Autonomy can be realised incrementally with progressively increasing levels of autonomy. The technologies required to perform UAV autonomous operations have been identified, emphasis being placed on technology solutions that would be possible within 5 – 10 years.
- A number of these technologies were identified to be critical, but are not yet at a Technology Readiness Level (TRL) allowing design and manufacture.
- The level of autonomy will depend upon the capabilities required of an autonomous UAV system, which is a function of the missions the system must perform.
- Technologies duplicating flight crew functions are critical for developing autonomy.
- Development cost can be roughly estimated by the TRL for a technology.
- Cost and risk for developing technologies to meet autonomous capabilities are dependent not only upon the level of maturity of the technology, but also upon mission and system requirements.
- Decision making, modelling, learning, and attack planning have the highest risk/highest cost associated with their development in UAV systems, but they also support the greatest number of autonomous capabilities.

- Technologies related to status assessment, weapons engagement, prediction, and mission plan update is relatively lower risk and lower cost.
- A number of technologies have been identified which are not uniquely critical, but contribute to different technical solutions for autonomous operations. It is therefore not necessary to develop all of these enabling technologies.
- An autonomous UAV operating within a network centric environment needs to behave with the same reliability and effectiveness as manned elements and ideally, should not require special handling.
- Due to the low TRL of recognising and comprehending natural speech, it is considered improbable that autonomous verbal interaction with civil air traffic control (ATC) can be developed to the level of reliability and integrity demanded by the Authorities. Until ATC interactions will routinely done by data link, autonomous crossing of civil airspace under ATC control is therefore not considered feasible.
- The proposed Technology Demonstration Programmes (TDPs) are an important step in the development of autonomous UAV capacities.
- It is most effective to conduct TDPs that improve the TRL level of technologies from TRL 5 to TRL 6.

2.1.3.4 Summary of UMV Missions, Roles and Tasks

Based on the foregoing, UMV roles and tasks can be broadly distinguished according to vehicle environments (UUV, UGV and UAV) and missions (ISR, Combat and Support Operations). These are summarised in Table 2-2.

Table 2-2: Summary of UMV Missions and Environments

Missions	Uninhabited Ground Vehicles – UGVs	Uninhabited Underwater Vehicles – UUVs	Uninhabited Air Vehicles – UAVs
Intelligence, Surveillance, Reconnaissance	Reconnaissance, surveillance and target acquisition Searching underground in caves, culverts, drains and man holes Searching collapsed buildings	Environmental data gathering Rapid environmental assessment Above and below water intelligence gathering Expendable sensor deployment Deployment of sonars near enemy naval installations ASW Bi-Static sonar operations ASW Track and trail Track asset movement Surveying areas in and around ports, harbours, ship lanes and landing areas Coastal and channel sonar mapping	Pre-strike reconnaissance Post-strike reconnaissance Battle damage assessment Stand-off operations Over target area operations Support for ground forces Beyond visible range (BVR) capability Support line-of-sight and beyond-line-of-sight reconnaissance Stand off ground Surveillance Report target and platform locations Sense and report a personnel and vehicle presence night and day Detect and report location and direction of threat systems acquiring, or targeting, the UAV platform
Combat Operations	Land mine detection and neutralisation Explosive ordnance clearance and disposal (EOD/IED) Urban warfare operations in confined spaces Breaching, earth working Casualty recovery Deployment of weapons or obscurants Firing of rifles, machine guns, grenade launchers and rockets Deployment as a decoy target Hostage scenarios Deployment of electronic counter measures	Mine countermeasures Mine hunting Mine counter measures prior to a naval assault Explosives ordnance disposal Kill enemy assets with torpedoes Mine neutralisation Obstacle neutralisation	Target identification Target verification Third party target illumination Strike Suppression of enemy air defences Destruction of enemy air defences Stand off jamming Stand off target acquisition Air combat, highly reactive against hostile manned fighter aircraft and enemy's UAVs Line-of-sight and beyond-line-of-sight fires and over-watch

Missions	Uninhabited Ground Vehicles – UGVs	Uninhabited Underwater Vehicles – UUVs	Uninhabited Air Vehicles – UAVs
Support Operations	Operations in contaminated areas and contamination assessment Detection and analysis of chemical, nuclear and biological assets Fire fighting Logistics – delivery to the battlefield of munitions, fuel, parts, food and water Security and patrol Deployment as a mobile communications link Deployment as a mobile power supply	Mobile signature range Anti submarine warfare – Trainer	VTOL combat search and rescue (CSAR) CSAR casualty transport (armoured cabin) CSAR escort protection with remotely controlled machine guns and IR-/TV cameras

2.1.3.5 References

[1] Lambert, P. (2002). The Role of Unmanned Vehicles and Remote Sensor Systems in the Future Underwater Battlespace. Commodore Paul Lambert Royal Navy, Director of Equipment Capability (Underwater Battlespace), RUSI World Defence Systems, April 2002. London, Royal United Services Institute.

[2] Strong, G. (2005). Selected Current and Planned Developments in Unmanned Ground Vehicles. Distillation, The Dstl Science Journal, Issue 9, pp. 32-42.

[3] Digney, B.L. (2002). Human Teaching Learning Machines: Apprentice Systems and Shared Control of Military Vehicles. In: The Role of Humans in Intelligent and Automated Systems, MP-088-04, Paper No 4, pp. 1-30. Proceedings of the NATO RTO Human Factors and Medicine Panel Symposium, HFM-084/SY-009, held in Warsaw, Poland, 7-9 October 2002. NATO RTO: Neuilly-sur-Seine Cedex.

[4] Carver, G. (2004). Some Human Factors Integration (HFI) Issues Arising from the Operation of Unmanned Underwater Vehicles (UUVs). In: Uninhabited Military Vehicles (UMVs) – Human Factors of Augmenting the Force. RTO-MP-111, RWS-010-OKN1. Proceedings of the NATO RTO Human Factors and Medical Panel Workshop held in Leiden, The Netherlands, 10-13 June 2003. NATO RTO: Neuilly-sur-Seine Cedex. March 2004.

[5] Tiltman, C. (2005). Review of UUV Work within the Research Programme. Distillation, The Dstl Science Journal, Issue 9, pp. 12-15.

[6] Posey, C. (2003). Robot Submarines Go To War, Popular Science, April 2003.

[7] Waters, M. and Taylor, R.M. (2004). A Bayesian Agent Approach to Autonomous Decision Making for an Unattended Cognitive Underwater Vehicle (UCUV). In: Uninhabited Military Vehicles (UMVs) – Human Factors of Augmenting the Force. RTO-MP-111, RWS-010-P4. Proceedings of the NATO RTO Human Factors and Medical Panel Workshop held in Leiden, The Netherlands, 10-13 June 2003. NATO RTO: Neuilly-sur-Seine Cedex. March 2004.

[8] Blackburn, M.R., Laird, R.T. and Everett, H.R. (2001). Unmanned Ground Vehicles (UGV): Lessons Learned. Technical Report 1869. SPAWAR Systems Centre, SSC San Diego, CA 292152-5001. November 2001.

[9] NATO, (2004). NATO Industrial Advisory Group, Study Group 75, Pre-Feasibility Study on UAV Autonomous Operations.

[10] Burridge, B. (2005). Post-modern warfighting with unmanned vehicle systems: Esoteric chimera or essential capability. RUSI Journal, October 2005, 150 (5). London, Royal United Services Institute.

[11] NATO, (2005). NATO SCI-124 Task Group, Architecture for the Integration of Manned and Unmanned Air Vehicles, Final Report. NATO RTO, Systems Concepts and Integration Panel. NATO RTO: Neuilly-sur-Seine Cedex.

[12] Curran, M. (2005). UAVs: A Critical Multiplier for Current and Future Forces. RUSI Defence Systems, Summer 2005. pp. 64-66. London, Royal United Services Institute.

[13] Francis, M.S. and Hirschberg, M.J. (2005). J-UCAS: Inventing a Weapon System for the Information Age. RUSI Defense Systems, Summer 2005. pp. 68-71. London, Royal United Services Institute.

[14] Hoogeboom, P., Herpfer, E., Fournet, P., Canafoglia, G., de Carvajal, A. and Hofkamp, C. (2005). SOSTAR, A European system for airborne ground surveillance. The Hague: TNO Defence, Security & Safety.

2.1.4 Command and Control

A recent analysis of C2 taken from an HF perspective, holds that C2 is rooted in the authority, responsibility and will of the human commander, including the human use of C2 systems [1, see also 2,3]. C2 is traditionally viewed from a technology perspective as a set of networking, information processing, and computational problems. As an organisational structure, C2 reflects the chain of command and concerns the delegation of authority and the expectation of responsibility and accountability. The chain of command is an important mechanism for accomplishing the transmission of commander's will. It is a process of C2 by which commanders exercise authority over forces to plan and direct operations. A key conclusion from this analysis is that C2 is fundamentally a human-centric undertaking, shaped by the nature of the military mission, by the security environment, and by the fundamental culture of the military itself. The concept of C2 centres around the actions of a commander who has been designated the authority to carry out those actions in respect of resources and subordinates, and who is expected to take responsibility for proper use of that authority. In this perspective, UMV technologies are command support tools and systems, and a vital aspect of C2. Thus, the underlying purpose of technology, such as UMVs, is to extend human capability – "whether it is the physical ability to act in the operational environment, the intellectual ability to make better decisions faster, or the interpersonal ability to communicate with distributed subordinates and security partners". The challenge is to ensure that UMV technologies are properly integrated with all aspects of C2 systems, but in particular, the human-centric nature of C2, so as to support efficiently and effectively the commander's

authority, and expectations of responsibility and accountability. For further detailed discussion of HF aspects of UMV C2 requirements and broader system-of-system issues, see Chapter 4.

2.1.4.1 NATO Air Command and Control System

The C2 of NATO air forces including manned and uninhabited aircraft and missiles, C2 centres, communications and sensors (and Command, Control, Communication, Computers, Intelligence, Surveillance and Reconnaissance – C4ISR) is performed by NACCS. NATO SCI-124 has considered the importance of NACCS for C2 of UAVs [4]. UAV systems are currently not part of the NACCS and are not managed as part of a manned strike package. In future systems, SCI-124 has concluded that UAVs will need to be closely integrated in the NACCS with manned aircraft if they are to operate in the same force package. Therefore, integration with NACCS needs to be considered in the broad concept of use for UAV systems.

NACCS is a hierarchical structure of headquarters with the operations centres of the System Command (SC) at the top and operations centres of the executing units at the bottom (Figure 2-1). This hierarchical structure consists of three levels: a planning level, in which the commanders deal primarily with the allocation of targets, objectives, resources and areas of responsibility to subordinate commanders; a tasking level, in which the commanders deal primarily with the assignment of tasks to resources for execution; and an execution level, in which the commanders deal with the control and management of the execution of assigned tasks. Four entity types Combat Air Operations Centre (CAOC), Air Control Centre (ACC), Rapid Air Picture (RAP) Production Centre (RPC) and Sensor Fusion Post (SFP) constitute the "core" of NACCS. Integration of UAV operations into NACCS has impact on UAV operations planning, tasking, tactical control, detection and tracking, identification, in addition to data transmission, data dissemination, and airspace management and traffic deconfliction.

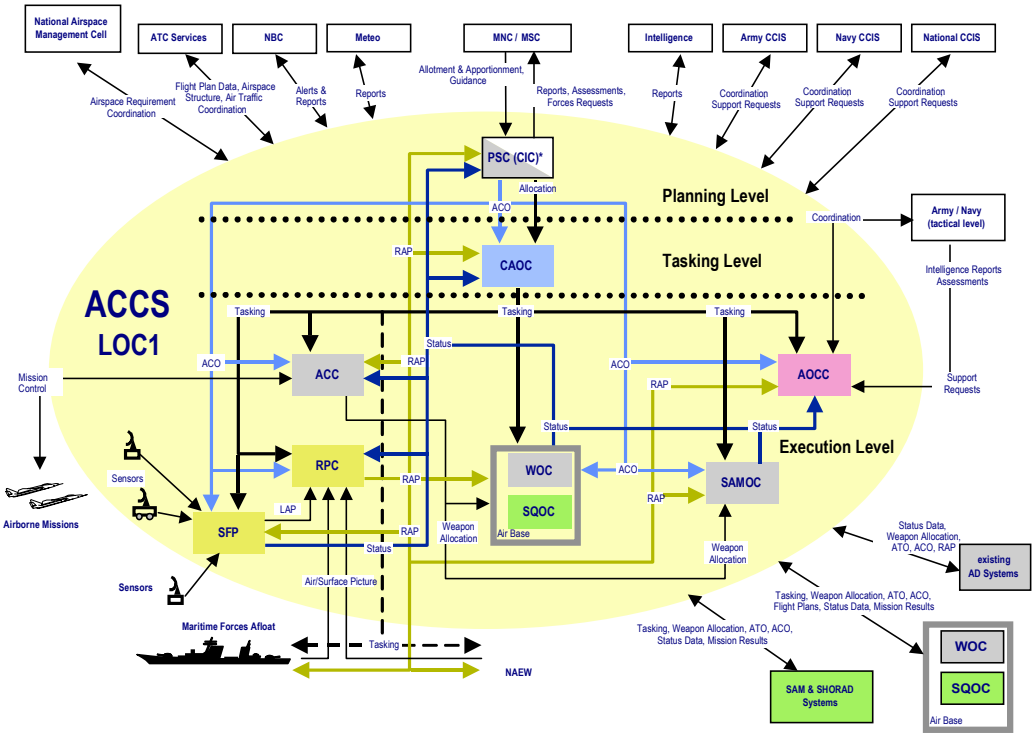

Figure 2-1: NATO Air Command and Control System – NACCS.

NATO SCI-124 have identified that NACCS will disseminate tasking information to all UAV operating locations. UAV sorties must be included in the Air Task Order (ATO) along with manned aircraft sorties for maximum combined effectiveness. NACCS will support coordination of UAV operations with manned aircraft and ground-based defences, including real-time C2 of UAV in-flight activities, and a command, control and communications interface between the NACCS entity and the UAV Control Station (UCS).

2.1.4.2 Interoperability

Interoperability is needed in Combined/Joint services operations to provide close co-ordination, the ability to task quickly available assets, and the rapid dissemination of resultant information at different command echelons. Current and legacy UAV systems are not interoperable. They do not have standard interfaces between the system elements, nor with C2 and ISR systems. NATO STANAG 4586 [5] seeks to define the standards for key system interfaces and functions in the UCS to communicate with different UAVs and their payloads, as well as different C2/ISR systems, to achieve levels of interoperability required by the system's CONOPS. STANAG 4586 includes a human-computer interface (HCI) style guide on best-practice. Multiple levels of interoperability are feasible among different UAV systems. Maximum operational flexibility can be achieved if the UAV systems support the following levels of UAV system interoperability identified by STANAG 4586, based on studies performed by AC/141 (PG/35) and NATO Industrial Advisory Group (NIAG), Sub Group (SG) 53:

- Level 1: Indirect receipt of secondary imagery and/or data.
- Level 2: Direct receipt of payload data by a UCS; where "direct" covers reception of the UAV payload data by the UCS when it has direct line-of-sight with the UAV or a relay device which has direct line-of-sight with the UAV.
- Level 3: Level 2 interoperability plus control of the UAV payload by a UCS.
- Level 4: Level 3 interoperability plus UAV flight control by a UCS.
- Level 5: Level 4 interoperability plus the ability of the UCS to launch and recover the UAV.

To be interoperable to a particular level, the UCS shall be compliant with all the requirements stated for all the levels up to that which is desired.

2.1.4.3 References

[1] HUM, (2005). HUM White Paper: Sciences of Command and Control. TTCP Technical Report, TR-HUM-16-2005, 30 September 2005.

[2] Pigeau, R.A. and McCann, C. (2000). Re-defining Command and Control. In: C. McCann and R.A. Pigeau (Eds.), The Human in Command: Exploring the Modern Military Experience (pp. 163-184). New York: Kluwer Academic/Plenum Publishers.

[3] Pigeau, R.A. and McCann, C. (2002). Re-conceptualising Command and Control. Canadian Military Journal, 3(1), 53-63.

[4] NATO, (2005). NATO SCI-124 Task Group, Architecture for the Integration of Manned and Unmanned Air Vehicles, Final Report. NATO RTO, Systems Concepts and Integration Panel. NATO RTO: Neuilly-sur-Seine Cedex.

[5] NATO, (2001). STANAG 4586 Standard Interfaces of UAV Control System (UCS) for NATO UAV Interoperability, NATO Military Agency for Standardisation, Draft Version 2.4 September 2001.

2.1.5 Legal and Moral Issues

Air Chief Marshall Sir Brian Burridge has expressed concerns about how international law may interpret the legality of future warfare reliant on robotic operations. During his closing address to the 'Iraq 2003 – Air Power Pointers for the Future' conference, the Air Chief Marshal presented his views on the use of UCAVs in combat, with the following observations:

> "*When we go into combat, we have got to be sure what we are doing is both legal and moral. I do not believe that, in future, even though technology will allow it, we will be allowed to indulge in robotic warfare. I simply do not see the international community regarding that as an appropriate way to fight. The notion of using UCAVs controlled from 10 time zones away to prosecute a battle is not something international law of the future will regard as acceptable. I think the notion of a person in the loop, the notion of positive ID, the notion of someone feeling the texture of what is going on in the battlespace, is going to be more and more prevalent……Overall, I think robotic warfare drives you away from what I term as emotional connectivity with the battlespace. My view is that winning the hearts and minds battle with the indigenous population requires this emotional connectivity*" [1].

Kennett [2] provides a detailed analysis of the legal and moral issues of fully autonomous UCAV operations. This analysis observes that the rapid technological advances mean that the concept of UCAV operating in a fully autonomous mode, engaging enemy targets without human interference, is nearing reality. It considers the implications in terms of technological plausibility together with the legal and moral aspects. This leads to the conclusion that although technology may allow waging a war which is free of risk, there are significant legal and moral hurdles, which will need serious consideration throughout the development of such systems. Consideration of the technological viability and legal constraints suggests that a "human-in-the-loop" system will be the most likely mode of operation.

The analysis considers use of UCAVs in combat with focus on the method of supervision of autonomous operations. It asserts that that there is a need to determine precisely what that level of supervision entails in conflict and how best to ensure that the human supervisor can interact efficiently and effectively with his uninhabited "charges". The argument considers that the possibility of highly reliable automatic target recognition (ATR) capability allows the technical possibility of fully autonomous target engagement. High levels of autonomy are projected for future UCAV operations. Indeed, the analysis quotes from informed sources that it will be technically feasible for UCAV to prosecute an attack fully autonomously with ATR when communications breakdown prevents human supervision and authorisation – but the question remains, "what would happen, for example, if during the period of lost communications the context of the conflict shifted significantly?" Surrender, shift of allegiances of major actors and renewed targeting intelligence are cited examples. It follows that the legal requirements for discrimination and humanity and accountability will always require that a human authorises the final decision to attack.

2.1.5.1 Legal Issues

The Law of Armed Conflict (LOAC) is a part of International Humanitarian Law. International Humanitarian Law is a combination of treaty law (binding on signatories) and customary (binding on all). Treaty law requires that for new weapon systems, *at all stages of development,* there is an obligation to determine whether its employment would in some, or all circumstances be prohibited by the protocol or by any other rule

of international law. All weapons systems must undergo a thorough legal review before entry into service. Legal advice is needed to ensure that not only that the end product has some utility, but also that no prohibitions exist as to the actual development of certain weapons. Kennett quotes Best [3, p. 62]:

> "*The history of warfare has been repeatedly punctuated by allegations that certain new weapons are 'unlawful', because in some way unfair by the prevailing criteria of honour, fairness and so on, or because nastier in their action than they need be*."

The development and ownership of UCAV platforms is unlikely to become an issue. What is important, Kennett argues, is that in the case of UCAVs, *the regulations and limitations concerning its use require legal review***.** Like guns, they are not necessarily illegal, but there are restrictions on who can own them, for what purpose and how they are employed. The use of UCAVs in conflict is similar to that of a manned platform. However, the major difference is that

> *"with a manned platform the pilot acts as additional layer of authorisation and he is ultimately held responsible for the outcome of his actions".*

Thus what the level of UCAV supervision entails needs legal review in the areas of discrimination, humanity and accountability.

2.1.5.2 Discrimination

The pilot is required to discriminate between what is a valid military target and what is not**.** Kennett [2] discusses how information is interpreted with reference to the "feel" of the situation, which would be difficult to replicate in machine information processing. This concerns naturalistic decision-making, where decisions are based on cognitive recognitional processes, involving pattern recognition, implicit and explicit knowledge, appreciation of meaning, visualisation and judgement skills, acquired previously through experience with similar situations.

> "*To do this, the pilot has a great deal of information available to him, some of which can only be interpreted by the 'feel' of the situation, which is sometimes referred to as the sixth sense. Whilst it would, in theory, be possible to harness the ability for a computer to add "feeling" to a decision through a knowledge base, it is unlikely that such a system could be fully trusted to deal with every eventuality. Additionally, proving that such a system is robust would be an enormously difficult task*".

It is believed that the legal requirement for discrimination is one that will be vitally important in the development of autonomous UCAVs. The concept of discrimination emerges from the Additional Protocol to the Geneva Conventions (Protocol 1), which states that:

Article 51(1): "The civilian population and other civilians shall enjoy general protection against dangers arising from military operations."

Additionally:

Article 51(4): "Indiscriminate attacks are prohibited. Indiscriminate acts are:

(a) Those which are not directed at a specific military objective;

(b) Those which employ a method or means of combat which cannot be directed at a specific military objective; or

(c) Those which employ a method or means of combat the effects of which cannot be limited as required by this protocol; and consequently, in each such case, are of a nature to strike military objectives and civilians or civilian objects without distinction."

This means UCAV development having to provide a capability to carry out some form of target identification to ensure discrimination between civilian and military targets. Developments in ATR seem certain to provide a robust capability against traditional military targets and camouflage tactics, but in modern asymmetric warfare, well-organised belligerents ignore the legal requirement under international law to be readily distinguished from the civilian population. They merge with the civilian population, they do not travel in identifiable military vehicles and they use sophisticated deception tactics. Also, military vehicles may be used as decoys to deliberately cause civilian harm, to attract public opprobrium against indiscriminate "aggressors" and to garner further public support for their belligerent causes. Thus, in modern warfare, it is very difficult for an autonomous machine to discriminate between civilians and military targets. Experienced human judgement is needed to assess complex risks, to consider both the immediate and broader context, to judge the consequences and implications of action, and if possible, to anticipate, see through and counter any new deception tactics. Consequently, any autonomous system will remain dependent upon 'human-in-the-loop' targeting decisions, where a human makes the ultimate decision to engage a target.

2.1.5.3 Humanity

The concept of humanity, like discrimination, also emerges from the Additional Protocol to the Geneva Conventions (Protocol 1), which states that:

> Article 35, (1): "In any armed conflict, the right of the parties to the conflict to choose the method or means of warfare is not unlimited."

and:

> Article 35, (2): "It is prohibited to employ weapons, projectiles and material and methods of warfare of a nature to cause superfluous injury or unnecessary suffering."

The 1980 Convention on Certain Conventional Weapons is the only instrument that actually prohibits or restricts the use of certain types of conventional weapons. Currently, this covers non-detectable fragments, mines, incendiary weapons and blinding laser weapons, but it is intended to be capable of evolving as technology and international opinion develop. Kennett suggests that as autonomous control techniques develop, their use probably will be subjected to a fair degree of scrutiny and restriction through this convention. It would be logical, therefore, to allow for flexibility in their concept of use as designs for autonomous UCAVs progress. This is a further reason why these systems should retain the ability for the human-in-the-loop to make the targeting decision.

2.1.5.4 Accountability

Kennett [2] argues that the most compelling reason for maintaining the human-in-the-loop targeting decision, is probably the requirement for accountability. International humanitarian law exists so that those who fail to respect the laws are open to legal recrimination. In combat, individuals are accountable for their actions. Accountability forces an operator to ensure that specific RoE are met before the initiation of any hostile action. Failure to adhere to RoE is likely to result in legal action against that individual.

With fully-autonomous UCAVs and without a human-in-the-loop, it is unclear who would be held accountable should things go wrong. Kennett asks: "*Is it the designers, the software writers, the commander who tasked the*

mission or the individual responsible for "supervising" the autonomous machine? Accountability might not be an issue were very highly reliable machines to be possible that do not make mistakes, but as discussed previously the possibly of enemy deception can not be discounted.

The 1922 Hague Rules of Air Warfare, which contains much customary law, states that "A military aircraft shall be under the command of a person duly commissioned or enlisted in the military service of the State; the crew must be exclusively military". This rule originally concerns the use of civilian crews to operate military aircraft. However, the underlying assertion that "military aircraft must be under command" is one that could apply specifically to UCAVs. This has significant implications for accountability. As noted earlier, it will be technically feasible for a UCAV to prosecute an attack fully autonomously with ATR when communications breakdown – but this means being willing to trust the UCAV to determine whether RoE are met – in effect, for it to continue its mission with nobody in command. This is to persist with loss of human sensitivity to shifts in context, and any resultant possibility of doubt about engagement, which would probably cause the human not to engage. Kennett notes: "*It is hard to imagine a machine that has doubt, especially after meeting pre-programmed criteria such as probability of identification and particularly when major shifts in context occur*". He postulates that "the reaction of the international legal community to the prospect of autonomous UCAVs continuing missions when communications have been severed and thus the vehicle is not under human command, is likely to be severe".

2.1.5.5 Legal Implications

Kennett [2] indicates that whether by customary international humanitarian law or treaty law, military forces must ensure that the requirements of discrimination and humanity are met and that a degree of accountability exists. The following conclusions are drawn from the analysis:

- Technology is moving rapidly to a point where the requirement of discrimination could be met to a high degree of reliability.
- This technology will be of limited utility against an enemy who is deliberately willing to blend into the surrounding civilian population.
- The ownership of UCAVs may be transparent to the concept of humanity, but their use is likely to attract close scrutiny in any forthcoming conflict.
- As the number and type of autonomous combat machines increases, it is unlikely that the international community will accept such proliferation without insisting on new legislation to limit or restrict their use.
- Accountability will remain one of the key tenets of future conflict, and whilst autonomous combat machines promise much, it is likely that humans will always be required to make decisions where humans may perish.

2.1.5.6 Moral and Ethical Issues

The study of moral issues (ethics) is "*concerned with or relating to the distinction between good and bad or right and wrong behaviour*" (based on the definition of 'moral' from the Oxford English Dictionary). In considering moral issues of using autonomous UCAVs, Air Chief Marshall Sir Brian Burridge refers to the term "*morality of altitude*" that was coined in to reference the disconnection of the pilot at 10,000 feet from the destruction caused by bombing on the ground [4]. This disconnection led to a lower incidence of psychological problems amongst USAF pilots than their US Army colleagues on the ground during the Vietnam conflict. He believes that the "*morality of altitude*" is at the heart of the debate of how international

law will interpret robotic warfare in the future. He concludes that "*Feeling the granularity of the battle-space is the key issue in interpreting the Rules of Engagement*".

The Air Chief Marshall poses the future possibility of the "Play Station" operator who may never have had actual combat experience, no connections with other operational units, and no shared operational experiences [4]. Furthermore, he expects that future highly autonomous systems will be reliant on an experienced programmer for their autonomy, who may not have any experience of combat operations in a manned platform. He notes that this will "*further remove the remote pilot from the system and place him within the industrial or military support base*". The Air Chief Marshall discusses how this exacerbates "*the disconnection of air power from the shared battle-space".* In considering the increasing lethality and persistence of UAVs, he questions how we stop the "*Play Station*" generation becoming the "*playground bully*" of the battlefield? He asks if this disconnection exacerbates the potential for the "*play ground bully*" in all of us to emerge. He contrasts the simplicity of "*drop and drag*" mouse actions on a lap top during remote reach-back operations, with the consequences on the other side of the world.

This discourse has some resonance with the social psychology of obedience and capability for human to act callously when disconnected from suffering and under pressure from authorities to inflict harm [5,6]. Milgram famously created a memory and learning experimental situation in which volunteer subjects believed they were administering electric shocks of increasing severity to another individual, as punishments for mistakes in two word pair reading lists. No shocks were actually administered, but the subjects were made aware of the discomfort caused by poundings on the wall. Quoting Milgram: "*With numbing regularity good people were seen to knuckle under the demands of authority and to perform actions that were callous and severe…… A substantial portion of the people do what they are told to do, irrespective of the content of the act and without limitations of conscience, so long as they perceive that the command comes from a legitimate authority*".

Drop and drag mouse actions at remote UAV control stations seem even more dissociated from their effects than Milgram's electrical switches. Unless the "*Play Station*" generation can somehow avoid "*the morality of altitude*" and "*feel the granularity of the battle-space*", we probably should not be surprised if they have the potential to become the "*playground bully*" of the future battlefield, and find UMV operations running into conflict with international law.

Kennett [2] reviews the argument for the morality of using autonomous UCAVs to kill without risk. This analysis concludes that, in some circumstances, even though technology and the law will allow such acts, morally, it would be indefensible. The analysis begins by recognising that killing in conflict presents a moral dilemma and that there is no universally accepted view of the truth. Feeling or subjectivity, as opposed to reason, largely determines the moral justifications – whether it feels truly right or wrong. The ethical implications will be dependent on the situation, ranging from supreme emergency to war of choice. In a war of choice, what is morally acceptable behaviour will be comparatively restrictive and judged on a sliding scale of necessity in the socio-political rather than legal sense. Using UCAVs in a war of national survival will be morally acceptable. During a war of choice, pitted against a technologically inferior opponent, using UCAVs will be acceptable for attacking targets that represent either an imminent or clearly identifiable latent threat (ballistic missiles, WMDs, massed armoured forces) – but although legally justifiable, it would be more difficult to feel justified attacking small groups of military personnel with UCAVs, decided by operators who, as Burridge [4] describes, are "*10 time zones*" away, removed from the threat, free of risk and without "*the emotional connectivity of the battlespace*". Kennett adds "*to open fire and to take life in such a situation does seem somewhat unsporting, even in warfare*". What emerges is that the taking of life, at a time and place of ones own choosing entirely without risk, although legally acceptable in war, is morally unjustified. There has to be an emotional connectivity with the decision, arising from having to endure feelings of risk, sufficient

to consider whether the decision feels right… "*Having to endure risk indicates no choice but to be emotionally connected to the battlespace*". It does not sound right to be able to wage war, risk free, through the virtue of technology, and in the course of doing so, to kill regularly so that killing becomes a de-personalised act. The analysis concludes:

> "*There will always be times when killing without risk in conflict will be necessary and entirely justifiable. However, outside the boundaries of fighting for national survival, such acts should not become the norm. To allow this would be morally wrong and risks devaluing the serious nature of conflict through a lowering of the moral value of killing and the value of human life*".

2.1.5.7 References

[1] Burridge, B. (2004). Iraq 2003 – Air Power Pointers for the Future – Closing Address. Air Power Review, Vol. 7, No. 3, pp. 1-15.

[2] Kennett, P.D. (2005). Autonomous Killing Machines – The Technical, Legal and Moral Implications. Defence Research Paper, Advanced Command and Staff Course No 8, September 04 – July 05, Joint Services Command and Staff College, March 2005.

[3] Best, G. (1983). Humanity in Warfare: The Modern History of the International Law of Armed Conflicts, London: Methuen & Co.

[4] Burridge, B. (2005). Post-modern warfighting with unmanned vehicle systems: Esoteric chimera or essential capability. RUSI Journal, October 2005, 150 (5). London, Royal United Services Institute.

[5] Milgram, S. (1963). Behavioural study of obedience. Journal of Abnormal Social Psychology, Vol. 67, pp. 371-378.

[6] Milgram, S. (2004). Obedience to authority: An experimental view. New York: Harper Collins.

2.1.6 UMV Use Cases

An articulation of the context of use of UMV systems is needed in order to provide a military relevant reference basis for considering HF issues. Use cases can be derived from existing representative military scenarios and associated "*snapshots*" or "*vignettes*". Military scenarios are ways of characterising future military threats and challenges. Scenarios are tools for operations analysis. They provide a means for evaluating capabilities and capability gaps, investigating military effectiveness and estimating cost/benefits for investment appraisals. In addition, scenarios are tools for systems engineering, providing the basis for the mission analyses used to develop understanding of system functions, information and user interface HF requirements. The selection of vignettes is important and entails the inherent risks of being unrepresentative. Selectivity risks biasing analysis, by introducing irrelevant or limiting focus, and setting overly restrictive boundaries and limitations to thinking. On the other hand, representative use cases, obtained from credible and knowledgeable sources, provide an efficient and effective means of communicating requirements and sharing understanding on likely contexts of use. This is particularly valuable for considering the relevance of new concepts and technologies. Development of system engineering requirements for UMVs is beyond the scope of the work of HFM-018. The purpose of this report is to provide a basis for discussion of scientific research on UMV technology and associated HF issues. Use cases are provided here to communicate likely contexts of use for appraisal of the military relevance of scientific and technical content of the report in the chapters that follow.

2.1.6.1 UAV Use Case

Military Applications Study NATO SAS-016, Future Operations with UAV Systems and SCI-124 on UAV C2 Architectures, have developed a Peace Support Operations (PSO) scenario to describe understanding UAV roles [1]. The PSO scenario is considered to be suitable reference use case for the air component of HFM-018 work. It is derived from a high level Peace Enforcement scenario and set during an early phase of the overall NATO operation. NATO forces conduct major air operations (offensive, defensive, support) using Composite Air Operations (COMAO) conducted from a Combined Air Operations Centre (CAOC). The COMAO aims to maximise the impact of a given force by concentrating efforts and enhancing survivability. This is achieved through mutual support, best available use of assets and saturation of air defences. The challenges are primarily from integrated air defences. This phase of the COMAO is illustrated in Figure 2-2 below. Figure 2-2 depicts the initial forced entry of NATO amphibious and airborne forces into the crisis area, the establishment of safe deployment areas and facilities, and the deployment of lead elements of the main PSO force and supplies into those areas.

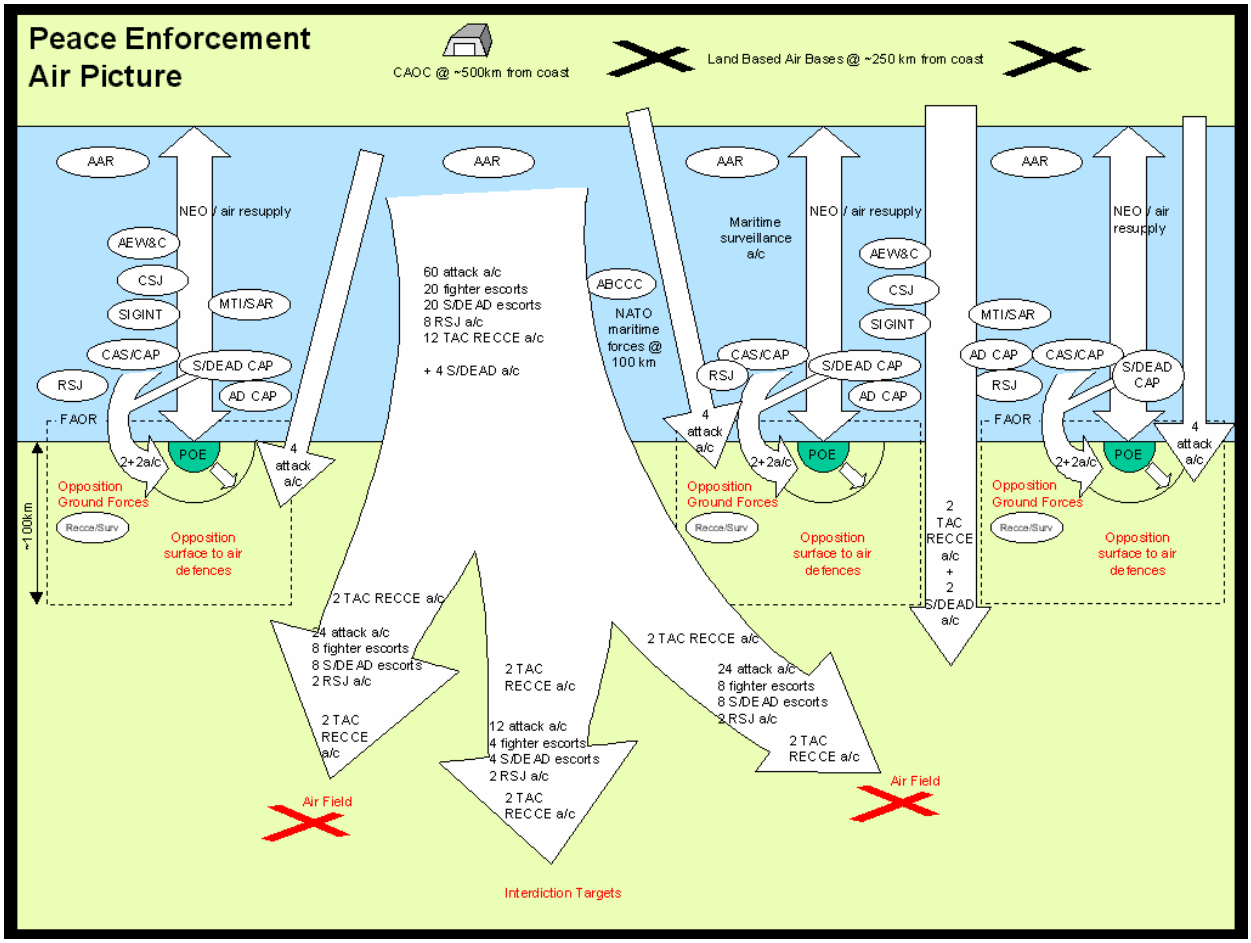

Figure 2-2: Peace Enforcement – Peace Support Operations at COMAO Level.

During this phase NATO forces seize and hold seaports and airports to be used for entry. At the end of this phase all entry forces have been deployed into the crisis country and the entry zones/bridgeheads are secure.

The operational scenario covers a limited period of time (10 days). During this time the various operations and missions take place. Although it is derived from the high level scenario, certain aspects of the operational scenario have been generalised in order to avoid making it too geographically and threat specific. At the time at which this 'snapshot' operational scenario is set the three main landing areas have been established and NATO forces have advanced up to 25 km from the entry zones.

The over-arching objectives which NATO air power must accomplish and the tasks and functions it must perform in the operational scenario are as follows:

- Neutralisation of the internal air threat (No Fly Zone);
- Defensive counter air operations;
- Offensive counter air operations against air bases;
- Neutralisation of ground-based threats to air traffic;
- Radar support jamming;
- Hard kill's/DEAD;
- Communications jamming support;
- Offensive Air Support for NATO entry forces and lead elements of the main PSO force;
- Deep interdiction of opposition ground combat power;
- Neutralisation of the maritime threat;
- Battlespace surveillance, airborne command and control and communications support;
- Air surveillance;
- Ground surveillance and reconnaissance;
- Maritime surveillance and reconnaissance;
- Battlefield tactical command and control;
- Re-supply of NATO forces;
- Emergency non-combatant evacuation;
- Combat Search and Rescue; and
- Psychological operations.

NATO forces must also deter intervention and attacks by states neighbouring the crisis country. As such, NATO air power is also held in readiness to deal with air and ballistic missile attacks from these neighbours, to interdict any ground attack, and to conduct operations for strategic effect against them. However, at the time at which the operational scenario is set no attacks have been launched by these neighbouring states. Consequently all NATO air activity in the snapshot operational scenario is related to the main Peace Enforcement operation in the crisis country.

The air defence and offensive air capabilities of the opposition forces have been substantially degraded by the time of this operational scenario. However, the opposition air defences have not attempted to mount a full-scale challenge to NATO offensive air operations. Similarly, the opposition has conducted only limited offensive air operations. Rather the aim of opposition air defence and offensive air operations has been to

inflict losses on NATO forces that although of limited military operational and tactical significance, the opposition believes will have direct strategic and political impact.

As a consequence the opposition has sought to preserve his air defence and offensive air capabilities by avoiding large-scale engagements, and by trying to make his forces difficult to locate and target. Consequently, at the time at which this operational is set, the opposition forces still have some air defence and limited offensive air capabilities.

2.1.6.2 Integration of UAV and Manned Aircraft Systems

UAV currently operate in segregated airspace physically separated from manned aircraft. SCI-124 report that this is due to the lack of clearance to operate in conjunction with manned aircraft and other UAVs, and overall inexperience with UAV operations. Integration with manned aircraft in the same airspace will soon be enabled by technological advances. Currently, the most common role for UAVs is ISR. UAVs are performing limited strike missions. Dedicated strike UAV platforms are planned for the mid-term timeframe. Therefore, SCI-124 have concluded that there is a definite requirement for the integration of strike UAVs with manned aircraft.

NATO SAS-16 used analysis of the PSO scenario and UAV capabilities to derive conclusions on UAV integration. An illustration of the integration of UAVs into the PSO scenario is shown in Figure 2-3. Different classes of UAV systems can undertake different types of mission/tasks dependent on payload (mass, type), range and endurance, speed and survivability (altitude, speed, signature, defensive aids). Broadly, they conclude that in the mid term UAVs will be able support only a limited range of attack missions. In long term, a wider range of attack missions could be supported, with greater autonomous operations, and tight rules of engagement, involving human-in-the-loop during target engagement phases. At the mission level, concepts of employment will depend heavily on mission and UAV system type. UAV systems can replace manned aircraft for various mission/tasks, placing fewer aircrew at risk. UAV systems can complement manned aircraft to enhance effectiveness of manned attack missions. They can perform high risk, high pay-off missions/tasks. Also, long endurance UAV systems can support more than one mission.

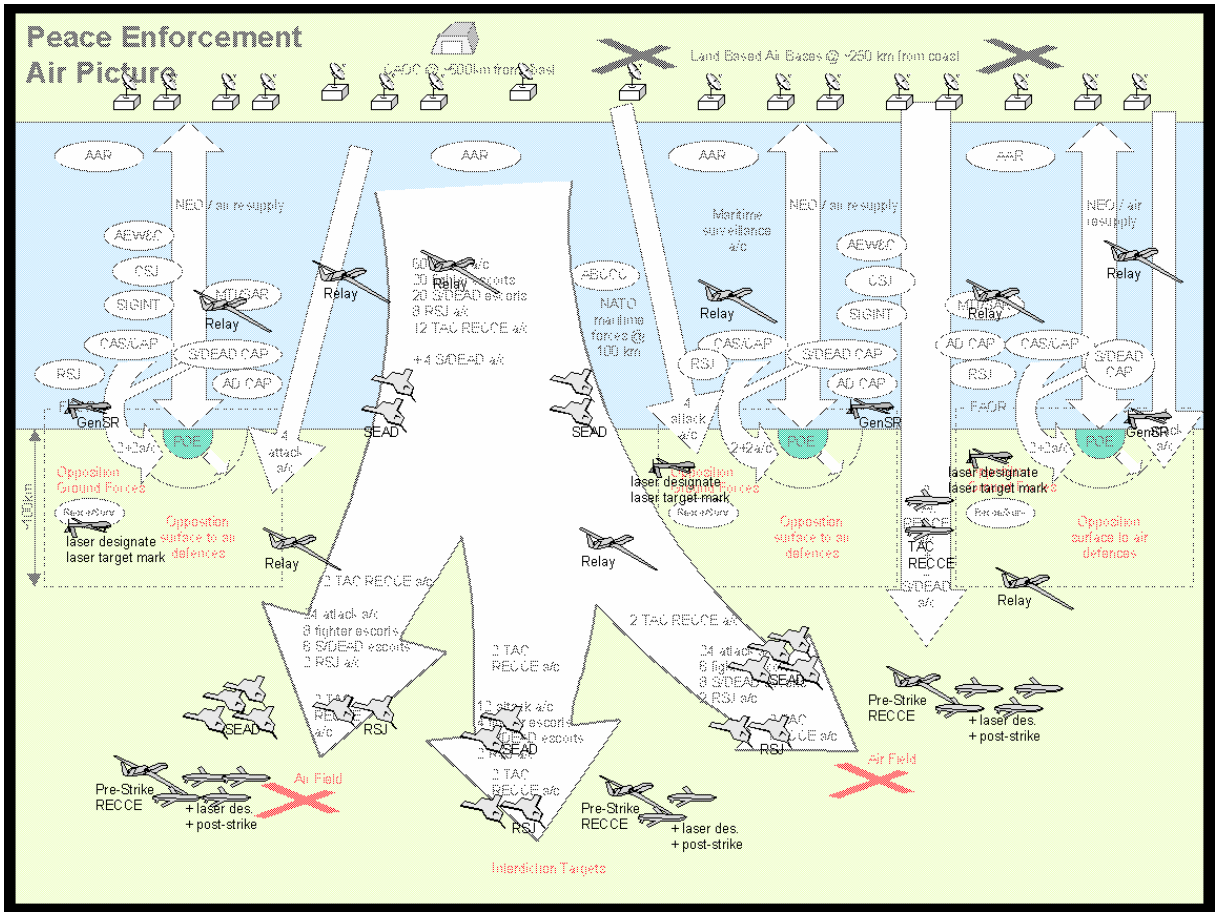

Figure 2-3: Integration of UAV Assets in PSO COMAO.

NATO SAS-16 concluded that many concepts require close co-ordination between the UCS and manned attack aircraft, but close co-operation is already needed on manned aircraft missions [1]. Some concepts involve hand-over of control to manned aircraft. Where hand over occurs multi-crew types offer a better option, and there is a risk of overloading the mission crew on airborne C2 platforms. Data links to the UCSs are a key issue and weakness (jamming). Beyond-line-of-sight requirements and latency problems add complexity, when detailed control is required. C2 authorities will need assistance to maintain the air picture. For the mid-term, there will be no close formation flying because of technical limitations and aircrew mistrust. Special corridors will be needed for ingress and egress, with rendezvous with manned aircraft in pre-planned areas. Special operating areas will need to be identified. Longer term, there will be greater formation coordination and integration with manned aircraft, since manned aircraft will remain in service for many years, and integration with the C4ISR system.

For COMAO mid term, SAS-016 observed that UAVs can replace various manned aircraft missions, but not those involving close formation coordination. UAV systems will use assigned corridors (routes and flight levels). UCSs will need to be integrated into the COMAO planning process. This will include consideration of: assignment of UAV mission leaders; routing (rendezvous areas and procedures, timings, air traffic procedures); reaction to threats; target area tactics and procedures; delay and cancellation procedures and options; communications and data link selection and de-confliction, including beyond-line-of-sight

requirements; UAV handover procedures where appropriate. The potentially large number of UCSs will need rationalisation and standardisation of the ground segment of UAV systems. UCS standardisation has been undertaken through STANAG 4586 activities [2]. Current COMAOs with manned aircraft require extensive pre-planning and have a degree of rigidity. The introduction of UAVs will shift the workload, but should not necessarily lead to overall increases. Longer term, UAV systems for attack missions (UCAV) will not need support, and there will be reduced demand for COMAO. Surveillance and reconnaissance UAV systems will form an integrated part of the overall C4ISR system. Direct links to offensive air operations will reduce the decision loop times of the sensor-to-shooter system. At the operations level, UAV system planning will need to be incorporated at the CAOC/Air operations level (Air Tasking Order – ATO; Airspace Control Order – ACO; Airspace Control Measures – ACM)). As a cautionary observation, SAS-016 noted that UAV systems may lend themselves to micro-management from higher command levels.

HFM-018 work on a human-centric framework for control of UAV operations required a degree of more detailed task specificity than provided in the PSO use case. The following UAV tasks were identified for a COMAO mission to attack an airfield in Article V operations, derived from SCI-124 analyses [1].

Ingress

- Control, Guidance, Navigation (ownship and attack aircraft);
- Replan;
- Communication (C2 MC, attack aircraft, other UAV UCS);
- System management (+contingencies);
- Self defence; and
- Target location.

Over Target

- Target registration, identification, verification, designation (for attack aircraft);
- Control, Guidance, Navigation;
- System management (+contingencies);
- Communication (C2 MC, attack aircraft, other UAV UCS);
- Sensor management;
- Self defence;
- Rules of engagement; and
- Battle damage assessment.

Egress

- Control, Guidance, Navigation;
- Communication (C2 MC, attack aircraft, other UAV UCS);
- System management (+contingencies); and
- Self defence.

2.1.6.3 UUV and UGV Use Cases

For the purposes of this report, the VSW MCM role provides a commonly recognised use case for understanding the application of UUVs. The basic task structure for MCM can be re-used to apply to UGVs in the MCM/EOD role.

Blackburn et al [3] describe the UUV VSW MCM (and EOD) task as comprising seven phases:

1) Deployment and distribution of assets;
2) Execution of a search strategy;
3) Detection of mine-like objects;
4) Classification and identification;
5) Neutralisation;
6) Verification and certification of clearance; and
7) Recovery of assets.

The UGV use case covers MCM and EOD tasks from high tide mark and above, providing route reconnaissance and access in support of troop advancement in the PSO scenario. The following tasks can be considered to apply to UGVs:

- Threat Assessment – close quarter/booby trap and hostile environments;
- Route Opening – approach dependent on collateral damage and speed of advancement;
- Route Clearance – approach dependent on collateral damage and speed of advancement; and
- Casualty recovery and management.

Understanding of how both UUVs and Unmanned Surface Vehicles (USVs) could conduct MCM is described in Carver [4]. This analysis reports that the foremost reason for preferring the UUV to a USV in the MCM role, is the requirement to conduct the mission initially in a covert manner. In many scenarios, it is not likely to be politically acceptable to conduct overt operations in another nation's littoral waters, thus making a semi-submersible UUV equally unacceptable. In any scenario, a variety of tactical options emerge, dependent largely on the level of autonomy given to the vehicle and the ultimate mission objectives. In the MCM role, the UUV will be deployed from a platform, or a harbour, and transit to its operational area. Characteristics of the vehicle associated with this phase include its range, speed and endurance, which must match the expected operational mission and tidal conditions. UUV capability is a function of size. The greater the capability in each area the larger the vehicle will be, unless new technology provides batteries or fuel cells with a greater power density. Once in theatre, the UUV will run along its pre-programmed survey path towards the objective. Dependent upon the vehicle's payload capability, degree of autonomy and rules of engagement, the UUV might then follow one of the following tactical options:

- Report the position of mines and wait for further instructions.
- Autonomously decide no clear path through the minefield exists and search for an alternate route to the objective.
- Dispose of mines along the swept path (from here the covert nature of the mission is lost).

The required operational role will determine the payload, which will influence the vehicle's size and the power required to complete the mission. In all events, the vehicle will be fitted with an inertial navigation system, collision avoidance sonar and high-resolution mine hunting sonar. Further, net enabled capability (NEC) will be provided by secure AComms. Communications may include the deployment of buoys or returning to the surface to communicate directly. The greater the autonomy given to the vehicle and the use of buoys will help to maintain the covert nature of the mission. Ordnance will need to be carried if the detected mines are to be disposed of.

Various UUV scenarios appear in the open literature. Carver [4] describes how, in the "harbour mine hunt" scenario, a number of small UUVs are launched to search for mines. Because total coverage is so important, the small UUVs would continually verify their position using GPS information provided by a larger communications/navigation vehicle positioned just outside the search area. Once the mines have been located, each small UUV (e.g., ALUV) could position itself over a mine and, after receiving the command, drop a small detonation charge to neutralise the mine.

2.1.6.4 Composite UMV Use Case

For the purposes of this report, HFM-018 (led by Lt Cdr A.G. Carver) have developed a composite scenario snapshot or "vignette", to provide a UMV use case to illustrate the possible functioning of UMVs. This composite vignette includes space, air, sea and land domains with UGV, UUV and UAV task elements. The tasks are summarised in Table 2-3. The task links are illustrated in Figure 2-4.

Table 2-3: Composite Scenario Tasks

Phases	Domains			
	Space	**Air**	**Sea**	**Land**
Period of Increased Tension	Surveillance of potentially hostile nation (PHN) – satellite to look for indications of hostile intent. Observe forces infrastructure – deploy satellites to observe PHN force dispositions. Observe forces manoeuvres – satellite to conduct survey of PHN forces.	Observe potential landing areas – use UAV to conduct initial survey of potential landing sites. Observe force numbers and manoeuvres – UAV to conduct survey of PHN forces.	Rapid environmental assessment – UUV to make assessments of ship movements and collect environmental data.	
Transition to War	Targeting – satellite to collect targeting data. Update observations.	Targeting – UAV to collect targeting data. Force observation.	Maritime survey – UUVs deployed to conduct more detailed survey of possible landing areas/locations. This could be a beach or a port if not heavily defended. Mine survey – UUV performs route surveys with synthetic aperture sonar. Identify mine like objects in path of route to selected beach head. Beach survey – UUV deploys UGV to gather initial beach survey data ahead of special forces. Port survey – UUV enters port and conducts visual survey of facilities and force disposition.	Targeting – UGV to collect targeting data.

Phases	Domains			
	Space	Air	Sea	Land
Conflict		Deploy air to ground weapons to destroy strategic and tactical targets – UAVs to carry offensive weapons into theatre.	Mine clearance – 1) UUV to continue mine survey. 2) UUV to conduct mine disposal. 3) UUV to provide verification and certification of clearance. Support beach landing – Large UUV to transport equipment and re-supply special forces ashore.	Route reconnaissance for access – UGV deployed to perform route surveys above water line in path of route from beach landing area ahead of special forces. Threat assessment – close quarter booby trap and hostile environments – UGV to identify mine like objects, EOD, and CBRN hazards in path of selected route. Route clearance – close quarter booby trap and hostile environments – 1) UGV to conduct mine disposal and neutralise EOD. 2) UGV to provide verification and certification of mine clearance. 3) UGV to provide detection and analysis of chemical, nuclear and biological hazards. Casualty recovery and management – UGV deployed to conduct CSAR, and casualty evacuation. Covert operations – UGV deployed to support of covert operations. Sense and report a personnel and vehicle presence night and day. Report target and platform locations.

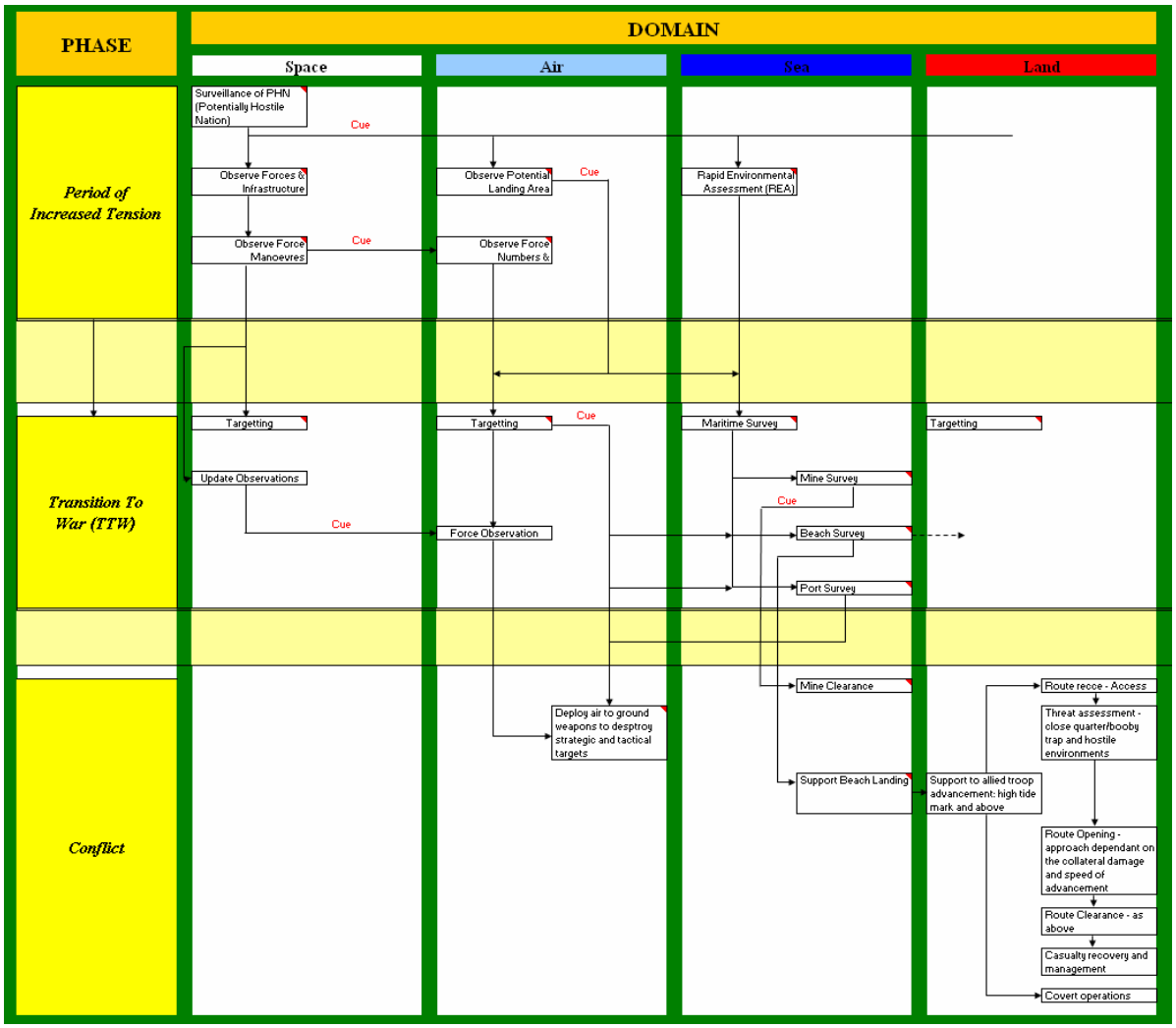

Figure 2-4: Illustration of Composite Scenario Task Links.

2.1.6.5 References

[1] NATO, (2005). NATO SCI-124 Task Group, Architecture for the Integration of Manned and Unmanned Air Vehicles, Final Report. NATO RTO, Systems Concepts and Integration Panel. NATO RTO: Neuilly-sur-Seine Cedex.

[2] NATO, (2001). STANAG 4586 Standard Interfaces of UAV Control System (UCS) for NATO UAV Interoperability, NATO Military Agency for Standardisation, Draft Version 2.4 September 2001.

[3] Blackburn, M.R., Laird, R.T. and Everett, H.R. (2001). Unmanned Ground Vehicles (UGV): Lessons Learned. Technical Report 1869. SPAWAR Systems Centre, SSC San Diego, CA 292152-5001. November 2001.

[4] Carver, G. (2004). Some Human Factors Integration (HFI) Issues Arising from the Operation of Unmanned Underwater Vehicles (UUVs). In: Uninhabited Military Vehicles (UMVs) – Human Factors

of Augmenting the Force. RTO-MP-111, RWS-010-OKN1. Proceedings of the NATO RTO Human Factors and Medical Panel Workshop held in Leiden, The Netherlands, 10-13 June 2003. NATO RTO: Neuilly-sur-Seine Cedex. March 2004.

2.1.7 Acknowledgements

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2.2 PART II – MILITARY RELEVANCE FOR UNINHABITED AERIAL VEHICLES (UAVS)

2.2.1 Introduction

Technology is a great source of power, which also is the reason why the military righteously is very concerned with it. New techniques create new tools for the human to utilise, new ways for the military to impose force. Together with the development of the logical circuit follows however a significant increase of the rate by which technological systems' ability to do new things increases. Systems are quickly getting performance characteristics that not only depend on concrete physical input, but also on arbitrary and abstract contexts. With the help of the microprocessor and clever programming skills, technology has expanded from advanced mechanics to automated machines that use logic and artificial intelligence. Technology has with that taken the great leap into an area that used to be strictly human business, the world of abstracts.

This development is likely to be just like any other development, humanity will eventually learn how to best use it and certainly benefit from it – but there will always emerge a few solutions along the way that probably would have been better off never being made.

There is however a certain peculiarity about abstracts: everything is more or less interconnected. It's quite impossible to state where one issue ends and the other starts. This means that almost every tiny little abstract rule somehow ends up being dependent on the supreme abstract dilemmas as aim, purpose and eventually even ethics and morale. Hence, it's not as easy to let technology perform only delimited parts of the abstract work as is possible with physical.

Technology will for certain be of great assistance in the traditionally strictly human area of abstracts, but the rules are different. This text argues that abstract tasks performed by technology must be designed with a greater amount of co-operation between human and machine, compared with typical physical work. Automated tasks depending on abstract contexts must be designed with great care. The more abstractly complicated a machine becomes the more thought must be put behind the design of the human role in order to create a machine that will be truly useful, even if the overall context differs from first assumptions.

The main issue for this text is that such thinking is believed to require a minor shift in focus when designing systems: it requires a human-oriented philosophy. Although the tone in the philosophy presented here might indicate that certain things are impossible, that's not the tenor, this is only to bring matters to a head.

Scope: The arguments need to be viewed differently for every context. Human control of a tiny little device working alone does in fact embrace these issues, although only very philosophically – but when it comes to complicated systems affecting really serious matters then this philosophy should have significant implications on just about everything from design to application. When, for instance, it's stated that only humans are allowed to judge in the topmost context and therefore need to be in control, it doesn't say that humans need to do everything. The human may justifiably have countless more or less completely automatic systems doing lots of good work, but this philosophy emphasises that there is an important question about how these systems affect the ability for the human to make sensible decisions and influence the situation.

From the Swedish UCAV study's point of view this material serves as one input among others to the compilation of our theoretical framework. Its purpose is to be a believed necessary counterbalance to the perceived technologically focused UAV community. It should not be seen as an official standpoint.

2.2.2 The Map of Relevance

The entrance of technology into the area of abstracts has introduced the possibility to develop automation, which in turn has made it possible to design uninhabited platforms. These technologies provide a lot of new exciting opportunities, not least for many typical military situations, which tend to be extremes both regarding performance and risk. There is however a significant risk of counterproductive solutions, regarding actual effect in reality. The relative strengths of automation and uninhabited vehicles are quite direct results of platform, vehicle or system characteristics and thus are comparatively easy to spot. The relative weaknesses on the other hand, are mostly more indirect consequences of loss of human control as consequence of conditions created by the characteristics of the systems. These consequential weaknesses predominantly become apparent in situations with significant uncertainties, especially when there are uncertainties in arbitrary abstract dimensions including context and politics, in situations with great complexity and sensitivity. They tend to show up in actual conflict situations where "reality suddenly comes and hit you in the face". Also, the only fixed planning parameter for future conflicts is that there is significant uncertainty about what the situations actually will look like.

To appropriately judge the relevance of anything, both strengths and weaknesses must be known and assessed according to a common ground of values. For something to be military relevant there must be a desired military effect that exceeds the cost of using it. And military effect is nothing but humans influencing other humans using military powers, commonly facilitated by technological systems.

The Map of Relevance consists of a collection of theoretical descriptions of a few believed fundamental conditions in [military] reality including an attempt to describe the subtle but important difference between designed and applied [military] effect. Appropriate effect is the key to relevance and this philosophy argues that the only relevant [military] effect is such that is intentionally achieved by [military] humans, where intentionally meaning being completely in charge of what's happening. If not, then the effect isn't really military and thus has no military relevance. That is, a human in charge is unquestionable and hence the reason to state it as an axiom.

2.2.3 The Human Axiom

The purpose of the human axiom is not to oppose automation and uninhabited systems since these technologies do render important capabilities. The purpose is to provide a foundation for the believed necessary thinking required for developing better systems containing automation. It's based on a human-oriented philosophy emerged from the issue of uncertainty and the theories of control described below.

2.2.3.1 The Philosophy

This philosophy may be interpreted somewhat controversial and is just because of that believed to be relevant. It's intentionally a bit provocative due to the ambition of being an eye-opener and needs to be read with that in mind. Because, it's not fundamentally important whether the word is autonomous or highly automated, whether mankind suffers from ugly technological hysteria or simply is a bit technologically focused, but the philosophy's underlying "crux of the matter", the essence that perhaps isn't really managed to be clearly conveyed, but that hopefully at least is written somewhere between the lines, is still very much the basis for the whole.

Technology exists solely to extend, magnify or complement human abilities. The use of a technological solution is never an end in itself. The purpose is always to serve the human and quite commonly the service is the gain of influence on other people that it provides, which apparently also is why technology is such a highly desired military tool. This influence is exercised either directly with system functionality, which then is the main military way, or indirectly like for instance through economical profit, which is the more commercial or political way. Either way, it is the humans who invented technology, it was done to serve the humans and technology has no own free will. That is, technology has no reason for existence on its own, it should never be an end in itself.

The modern world however, appears to be suffering from something that may be labelled technological hysteria. The disease proves itself as constantly creating a competition between technology and humans, by the rules of technology. Performance is judged according to what the technology is designed for and human participation is then excluded since technology is found to perform better. This may be the case when leaving out the fact that some odd quirks of life called reality most certainly will pop up and fundamentally alter the situation, not unlikely into something that the technology wasn't designed for. Then the drawback becomes clear. The human has no possibility to interfere when excluded from participation and the device that was meant to be helpful may instead cause severe problems. The aim in designing these systems should therefore be to allow for a natural interaction and cooperation between the human operator and the technology. Over-explicitly, technology should take care of details and the human should do the thinking and planning, although very well served by a lot of details handed by the technology.

This hysteric disease tends to end up in the technological imperative, what is possible is a must. Where it's possible to replace human appearance it's done. The healthy approach would instead be to investigate where and, equally or even more important, how technology best could help the human. Since technology doesn't strive for it by itself, this, what from a human perspective must be seen as a clearly unfavourable order, is maintained by the humans themselves, which solely is a reason good enough to call it hysteria.

The complete hysteria is reached when the aim is to develop autonomous systems, since autonomy means self-governing. And ultimately, for anything to be truly autonomous it must be able to raise mutiny and even to decide for its own set of reasons to kill its commander. That is obviously not what mankind wants with its technological solutions. The highest form of automation is not necessary autonomy since that implicitly implies loss of control, which is a considerable price to pay. Furthermore, automation is always automation and it has no private desires or personal values that may constitute truly autonomous decisions. The highest form of automation should therefore be designated nothing else than completely automatic systems, although the automation may be very advanced and contain all sorts of artificial intelligence. Furthermore, automatic does not necessarily mean without human interaction since a system can very well be simultaneously highly automated and very interactive. The character of the interaction is probably the core issue for the possibility to maintain control of systems with automation containing complex abstract rules. Advanced automation and

highly automated systems create great prospects, but technology must always and unconditionally serve the human and thus be completely under some humans' control, which means it should never be autonomous!

Although this phrasing argumentation may seem like splitting hairs, it does serve a specific purpose. The word "autonomy" is perhaps most commonly used to denote something that is more than "just" automatic, something that is as independent as possible, which might be a completely correct use of the word. But, independent need not necessarily imply uncontrolled, which the technological hysteria tends to impose. It is the use of the word autonomous together with the competitive environment between humans and technology caused by this technological hysteria that makes it dangerous. This argumentation illuminates among other things the subtle but important difference between autonomous, as in independent and unconstrained, and automatic, as in independent within certain limits.

This philosophy is virtually nothing but a slight rephrase of Isaac Asimov's famous three "laws of robotics" from 1942, or four, since he wrote the zeroth law in 1985. The phrase "robotics" is easily identified as being identical to automated systems, and these laws are:

- First: A robot may not injure a human being, or, through inaction, allow a human to come to harm;
- Second: A robot must obey the orders given it by human beings except where such orders would conflict with the First Law;
- Third: A robot must protect its own existence as long as such protection does not conflict with the First or Second Law; and
- Zeroth: A robot may not injure humanity, or, through inaction, allow humanity to come to harm.

One common objection to these laws is that they inhibit the use of "robotics" as tools for police and military work, since such inevitably include the use of force that sometimes deliberately harm human beings. According to this philosophy should a rephrase then be that robots, i.e., automation, must never autonomously violate these laws. If they are to be violated, there must be at least one human being in charge, which has control, of what the automation is doing. Hence, the automation must never be autonomous, in the word's full sense.

2.2.3.2 The Automation Paradox

One core thing that fundamentally separates human intelligence from the artificial counterpart is the fact that the human has the unique ability to always be able to apply everything in a greater or different context. Artificial intelligence, i.e., highly advanced logic, will never be able to handle something that it's not designed to handle. Human participation will therefore from a human perspective always be essential and automation is because of that forever constrained to be nothing but an assistant. This is here stated as the automation paradox, that regardless the capability of automation it will always require human guidance. Because, even the most advanced adaptive self-learning and artificially intelligent system will only be able to learn what it's been designed to learn. If mankind eventually succeeds with something that looks like breaking this paradox and manage to develop systems that are able to learn arbitrary things, including to develop its own ambitions and desires in order to make autonomous decisions, then perhaps the truly autonomous system is invented, and the inevitable question emerges: Is that what mankind actually wants? The paradox remains!

2.2.3.3 The Human Paradox

The automation paradox may be rephrased as that it's impossible to write rules for every possible situation, or even for every part of any situation. That means that there will always be situations, or parts of every

situation, where automation either will act ambiguously or according to an improper set of rules. On the contrary, a human being is able to apply the known set of rules in an arbitrary context and fill the gaps with what's best labelled as intuition, experience and common sense. One can always argue whether such a decision is the best or if an automated decision without any subjective feelings is better, but bearing in mind that life in general and military activity for certain is nothing but human beings interacting trying to influence each other, there is virtually no option. The topmost context is human life and it's only participating humans that are allowed to judge in that context. That is, decisions with adherent uncertainty affecting humans must ultimately be based on human judgement, which consists mostly of intuition. And it's equally illegitimate if technology autonomously makes these kinds of decisions or if it somehow reduces the human ability to make sensible judgements. The paradox then becomes that regardless of how subjective and irrational, i.e., how technologically lousy, human decisions are, they still are the only correct, valid and allowed ones at the highest levels of abstraction. When there are no or unclear predefined rules, when there is true uncertainty, life itself, which was stated as the topmost context, is humans acting on intuition, regardless of whether it's right or wrong.

2.2.3.4 The Principle of Uncertainty

It is by nature impossible to exactly predict the future, even in the shortest of terms. That is, every situation contains a certain amount of uncertainty, which here is defined as the concept of Situation Uncertainty (SU). Furthermore, every situation alters continuously, which has the consequence that uncertainty is self-generating. Uncertainty increases with amount of time in advance, probably exponentially.

Nearly everything in the every-day life in the civilian society is benign or well behaving, at least in theory. The situations contain natural damping. This is because everyone involved is supposed to want everything to work properly. The situations become self-regulating. It may be seen as a stable system. System shortcomings are avoided if possible and otherwise handled in an as good as possible manner. Which means that for a system that will work in 95% of every known case the probability of the other 5% to occur is reasonably low. On the other hand, all kinds of conflict situations, i.e., business situations and negotiations in general, but especially military situations are more like malignant or evil behaving. This is because there is at least one opponent that will do everything possible to exploit any kind of weakness. The situations become self-escalating. It may be seen as an unstable system. System shortcomings are particularly rewarding weaknesses that are searched for, and tend to be found and exploited by the opponent. Which means that for a system that will work in 95% of every known case the probability of the other 5% to occur is quite significant.

That is, conflict situations have greater probability for unfavourable situations to occur and greater probability for severe and escalating consequences of these situations. Hence, situation uncertainty is from the start greater in conflict situations compared to normal every-day-life situations, and furthermore, the uncertainty has most certainly a greater rate of increase as well. Therefore, automated solutions that work acceptably in civilian environments will not per se function properly in conflict situations.

However, although it's virtually impossible to completely eliminate situation uncertainty, it's definitely possible to constrain it and keep it under control by reducing the number of degrees of freedom. That is, the uncertainty is possible to grasp and handle if the situation is simple enough. In other words, uncertainty may possibly be under control if and only if the worst-case scenario is acceptable. The question to ask in order to find the situation uncertainty is then, how wrong can it possibly go? If there is uncertainty about what to do, the worst thing that can happen is that wrong thing is done. If there also is uncertainty about where to do it and when to do it, the worst thing that can happen is that wrong thing is done at the wrong place and at the wrong time, which probably is just about as bad as it could get!

2.2.3.5 The Principle of Control

It's a significant difference between to have control and to perform control. The state of having control may perhaps be the result of the work done by performing control, but it's not a necessary consequence.

For a human to be able to have control there must be awareness about the situation and about the entity to control together with a capability to control it. When it comes to controlling humans the capability to control may possibly be replaced with trust. Regarding technological systems trust is knowledge about and personal experience of the systems' capability to function both inside and outside its intended envelope. That is, trust for the systems' robustness. For a human being it's possible to have trust in that this person will act to the best of abilities, according to a common ground of values, even in unknown and complex situations. This includes the assurance that the human will break a commitment and do whatever's found to be necessary if the situation demands it.

Trust for a system is different. It will do what it always does, if possible, which sometimes is a quite reassuring behaviour – but it will do that even if the situation happens to require something else, unless the system actually is prepared to alter its performance, which then makes that kind of situation not really unknown. This is especially disturbing for uncertainties in the higher levels of control, uncertainties about what to do and why it has to be done. A systems preparation to alter its behaviour is commonly an implementation of a certain amount of rules, which then is to take a selected amount of abstract issues into account. Abstract issues are earlier stated to have the peculiarity that another rule may have the power to alter the present ones.

The overall capability to control consists of designed possibility and human ability to control. Human ability consists of awareness together with experience and skill. Humans tend to gain experience and skill while training for ability, which is done by actually utilizing the possibility to control. Furthermore, the situation awareness does profit from experience as well. That is, to have control the human is likely to require the experience of some hands on work of controlling, since that's what creates the ability that constitutes the capability that is required to actually have necessary control. This is probably a core foundation for the irony of automation. The challenge then becomes to design automation to perform tasks that relieves the human from workload in a way that it simultaneously keeps the human in the loop well enough to maintain control, which may appear to be contradictory. The key is here believed to be to carefully design the character of the interaction, the intensity, level of abstraction and capability of adaptation.

Levels of abstraction and levels of control are phrases that tend to be slightly deterministic. In such models the interaction or control tend to be viewed as being made at a certain level only, which is somewhat framing. The concept of "layers of control" might help in viewing this as concurrent or parallel processes. Control and interaction are performed at all levels, or in all layers, simultaneously. Automation within a layer of control may help a human and reduce the workload required to do that task, or even completely replace the human and do the entire work, but automation does always have design limitations when it comes to the capability to handle unpredicted inputs, which commonly is the outcome of some higher layer. The problem is to design the automation to avoid making it more difficult for the human to discover and add the new inputs to the matter and to tweak the performing of the task according to the new situation. Furthermore, if there is automation, as opposed to humans, that transfers the information between the layers as well, then the risk of doing the wrong thing at the wrong place and at the wrong time, described above in the section about uncertainty, is significantly increased. Therefore, the transfer between the layers need to take the entire context into account and follow the overall purpose even when additional and unforeseen parameters appears. It therefore needs to be controlled by humans. This becomes more important the higher the levels of control that are involved.

Another way of maintaining control is to set boundaries, to state constraints. For instance, a completely automatic system that is uncontrollable when fired, but that has clear constraints and a robust behaviour may still be considered under control. The danger lies within the ambition to develop more flexible systems and the adherent design of more complicated constraints, which then may introduce uncertain behaviour in complex situations.

2.2.3.6 Designed and Applied Effect, Robustness, Versatility and Flexibility

A system has certain designed capabilities that possibly may give a designed effect, which is when it performs as it's supposed to do, in an environment (both physical and contextual) that it's supposed to have. Capability is the prerequisite for effect to occur, at all. One way of describing robustness is when the system still will perform even when the environment changes into something less favourable. Robustness is some built in assurance that things possibly will function even when the situation is starting to get tough. Versatility can be said to be when the system is capable of doing more things than what really is necessary. And, versatility together with robustness creates the potential for flexibility.

Flexibility however, requires the ability to adapt. Automation is able to adapt to what it's designed to adapt to, which creates what accordingly need to be labelled designed flexibility. True flexibility is then a strictly human quality. Together it forms a flexibility that may be applied among the uncertainties of reality, an applied flexibility.

Furthermore, the human's ability to change the context is also a source of creativity. Another viewpoint and unpredicted input may create opportunities to improvise and apply system capabilities in a way that gives a certain advantage in precisely that situation, to create an applied effect.

Automation capability is by definition part of the designed effect since it has the capabilities it's designed to have. To further illustrate the concept of applied effect, consider the following example: An ace operator is not the one that always performs as supposed to, facilitating the systems designed effect. The ace is the one that's able to take advantage of something unforeseen in a situation. This is obtained by being truly flexible and able to utilise system capabilities, sometimes in ways not intended when designed, which includes relying on robustness and exploring versatility. In this way it is possible to create an applied effect that may perhaps be applicable in that unique situation only. Designed effect is the necessary power to outbalance the armament race and applied effect is what wins the fight!

2.2.3.7 The Principle of Necessity – The Human Axiom

The Philosophy, the Principle of Uncertainty and the Principle of Control together indicates one obvious conclusion. There is really never a question of whether or not it should be a human involved in what a system does. The only relevant question is how the human should be involved and hence, yet another principle is defined. The Principle of Necessity, which then says that it's absolutely and unquestionably necessary that the human has control, that there is a human in charge. It is this unquestionable nature that makes the word axiom so compelling, it's just that's the way it is, it's fundamental.

Every reduction of human control over technology is by definition negative. If control, in defiance of that, is to be reduced, it must be completely justified.

2.2.4 Platform Characteristics

The perhaps more common phrase "unmanned aerial vehicles (UAVs)" is strictly speaking wrong. It's in reality nothing else then a separation of the human and the platform, which makes "uninhabited" a more

suitable word. Still, it's all about a separation that may be more or less complete and which implies different characteristics depending on the design of the system. Besides physical characteristics, where the inherent possibilities coming from not having a human onboard are the desired effect, separation states the prerequisites and creates the conditions, for control of the platform.

If an uninhabited platform is completely automatic, i.e., there are no means by which to control it after launch or after a certain point in time, a complete separation in time has taken place. The separation in space states that even if there is a communications link that makes it possible to somehow control the platform there will be a change in the character of control compared with not being separated. That is, separation is done in time and space and the consequence are a change in the character of control, which may vary over time.

It's the character of the platform that states the type. The difference between inhabited and uninhabited platforms is settled by a single parameter, which naturally is whether or not there is a human onboard. The difference between a missile and an UAV is not that simple. It could perhaps be determined by the use-once factor of a missile. Another possible identifier is that a UAV is more of a platform, it's the payload that does the work and it may perhaps be replaced. Compared with a missile, which is more or less entirely dedicated for its task. The character of the interaction may be used to state the difference between a remotely piloted vehicle (RPV) and a UAV, where the former is more directly controlled at a lower level of abstraction than the latter more highly automated kind of vehicle.

2.2.5 Interaction (Control) Characteristics

Separation in space of the human and the platform inherently creates a reduction of the extent of the interaction between them, a reduction that is dependent on the capability, i.e., bandwidth, of the control link. Even with an unlimited amount of bandwidth there will be a reduction in interaction, a reduction that is dependent on design. Due to the physical separation, the only possible interaction is what's designed to occur. That is, the system will only convey information that it's designed to convey and reality will always bring at least one more relevant piece of information to the situation. What have been lost are very often alternative kinds of feedback channels and especially all sorts of subtle, abstract and intuitive ones, which commonly are quite underrated.

Separation in time of the human and the platform is merely when the separation in space occurs. Since separation in space creates a change in the character of control the timing issue states when this change takes place. For completeness, the character of control may vary over time, but typically it's a question of a time-dependent reduction of the possibility to interact. Furthermore, it may come to a certain point in time when the possibility completely disappears, e.g., "fire and forget", and where situation uncertainty inevitably starts to self-generate. The character of control, in other words the possibility to interact, is a tool used to handle situation uncertainty. The informative part of the interaction, i.e., the feedback, is the base for reduction of uncertainty and the possibility to control is the means by which to act or react.

The characteristics of the control may be described with its stability, continuity and robustness and is very much dependent on the characteristics of the interaction. The characteristics of the interaction may be described with its intensity, level of abstraction and possibility of adaptation.

To summarise, the physical separation of operator and system puts constraints on the possibilities to interact with the system. Interaction is a major part of "The Principle of Control".

2.2.6 Relative Strengths

The relative strengths of uninhabited vehicles are almost without exceptions spawned out of the actual separation of the human and the platform. An obvious exception is the class of strengths that comes from the perhaps most common aim of automation itself, i.e., relief of strain, reduction of workload, which obviously is one of the main purposes for automation within inhabited (manned) systems.

The relative strengths are very well summarised with the well-known triplet – dirty, dull and dangerous – but these words need to be unfolded into something with more details. First it's possible to identify that there are direct and indirect strengths. The direct strengths may be sorted into the three classes of time, task and environment. The indirect ones are mutually dependent on each other, but could be described with cost, risk and importance (military and political).

Automation has no common human requirements for food, rest and convenience, which mean that many human time limits are possible to be ignored. Human limits in long time attention and physical exhaustion together with performance variances over time may be reduced as well.

Tasks may be unsuitable for humans in quite many ways. For instance, too demanding characteristics may be unsuitable, like the need for extremely quick response, e.g., unstable platforms. Or physical strength may be unsuitable, e.g., tasks requiring hydraulics. Too simple tasks – monotonous ones, or tasks that have nothing or little relevance for the overall situation – tend to make humans bored and perform poorly.

The environmental strengths are many and adjoin to the risk parameter. Every situation where humans would suffer or be unable to exist is in some sense a bad environment for a human being. This includes, for instance, very high or low pressure as in great depths, high altitudes or high acceleration forces, i.e., high Gs. It includes toxic environments as in N-B-C environments or extreme temperatures. Or it may be unsuitable size requirements, i.e., too small for humans to fit. Unhealthy environments are those that create a certain risk for a human if exposed to it and the most common military one is that of being opposed and perhaps fought down.

The indirect strengths are for instance, while being without the risk of human loss, having the possibility to take risks. However, there is always a cost committed to most things and advanced, capable and in reality useful systems tend to be quite expensive, with or without a human onboard. That is, it comes down to overall importance, like economical importance and political concern. An important matter may justify the risk of loosing expensive equipment. A political extremely sensitive matter might possibly even justify the risk of loosing human life.

These relative strengths are in certain situations so important that they may outweigh just about any weakness, if for no other reason just because there are no other options. The philosophy above doesn't in any way oppose this. It just points out that if the adherent weaknesses are well known, it might be possible with clever design to reduce their consequences.

2.2.7 Relative Weaknesses

Most weaknesses of uninhabited systems are consequences of loss of control depending on automation either forced by the separating design or by unsuccessful automation efforts that sometimes are driven by the technological hysteria, i.e., proofs of the irony of automation. Either or, it has something to do with automation and character of control, which certainly not is something reserved for uninhabited systems. These problems are undoubtedly present in manned systems as well – but the separation of the human and the uninhabited platform more or less forces extensive automation to be done, and this sometimes in areas with

less experience from actually using automation. That's why the problems tends to be at least one order of magnitude greater.

Modern conflict situations with great complexity and sensitivity quickly alter relevant parameters. Situation uncertainty is significant and quickly self-generating. Predictions, early decisions and logical rules that at one moment are correct and relevant quickly become obsolete. In such situations there is a severe risk that automation assumes or disregards something that is uniquely important and perhaps important at exactly that situation only. Furthermore, it's not unlikely that there will be rules of engagement (ROE) that for some reason, and sometimes unintentionally, will inhibit the use of such a system, which in turn will create undesired disadvantages.

These indirect weaknesses are connected with the indirect strengths as well. Loss of control due to automation is in itself a risk of doing wrong, which must be judged against the risk of doing nothing or against the risk when using humans, etc. The weaknesses are mainly lack of robustness in the higher contexts, which doesn't necessary need to be opposed with removal of automation. Lack of robustness due to automation problems is perhaps more the result of not addressing an issue than of addressing the issue wrongly. The unique human ability to apply every matter in a wider context makes handling uncertainties in the overall context very much a strictly human business. Automation should help humans handling such by always being designed to support human control as opposed to being a replacement for the human.

2.2.8 Summary and Relevance

Relative strengths follow quite directly from separation of human and platform. Relative weaknesses are mostly consequences of loss of human participation that more or less follows from the same separation. Strengths are direct results from technological design and are thus easily spotted. Weaknesses are indirect, sometimes abstract and often not recognised until tested in the dynamic environments of real situations with true and actual uncertainties that are context dependent.

Relevance of technological solutions, especially military ones that deliberately cause harm, needs to be judged thoroughly. In order to judge something, both strengths and weaknesses need to be known. Military effect is effect accomplished by military people, in modern times most commonly founded by technological systems. Relevant military systems are systems that complement the military people. Furthermore, identified technological strengths are easier to correctly exploit, will have better effect and will be more difficult to oppose if they are put into context, if their corresponding weaknesses are fully comprehended and where possible addressed. There is no military system more relevant than the one that actually wins the fight.