Chapter 1
Introduction

"The whole art of war consists in getting at what is on the other side of the hill"
The Duke of Wellington, 1769-1852

The intrinsic demand for automated, robotic and unmanned systems is largely driven by applications that are inherently repetitive, unpleasant, or dangerous. At present, these tasks typically include agricultural, container handling, intelligent transportation (repetitive), scientific exploration, mining, waste management, (unpleasant), search and rescue, fire-fighting, and military applications (dangerous). Additionally, as many of these applications necessitate the employment of vehicles that are relatively expensive, the additional cost of the automation components and integration is often modest relative to the gains made by better use of the platform. This tends to auger well when establishing robust use cases for such systems, particularly in the commercial arena. For military applications there are a number of other drivers:

- Autonomous UVS have the capacity to extend the reach and access of operations, thereby reducing risk to warfighting personnel;
- If appropriately networked to each other and to higher value manned platforms, they can significantly increase coherency of effort and operational tempo, thereby potentially offering much higher operational effectiveness and increased capability across the battlespace;
- In the longer term, they could reduce the cost of acquisition and operations; and
- They are one of the few areas of current technology that legitimately qualifies as having a potentially revolutionary impact on military operations

In 2001 the US Congress was sufficiently persuaded by the military potential of these systems that it directed its Department of Defense (DoD) that one third of all operational deep strike force aircraft must be unmanned by 2010 and one third of its

A. Finn and S. Scheding: Develop., Challenge. for Autonom. Unmann. Vehicles, ISRL 3, pp. 1–4.
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operational ground combat vehicles must be unmanned by 2015.[1] While this may not be achieved in terms of fully autonomous UVS, the deadlines have applied considerable pressure on the US military to introduce large numbers of tele-operated or semi-autonomous UVS into capability, and many nations will almost certainly follow their lead. As technology improves the level of autonomy will increase.

As a result, autonomous and Unmanned Vehicle Systems (UVS) now play a key role in the modern battlespace and would have allowed the Iron Duke to spend much more of his career pondering other matters. Furthermore, their contribution in recent conflicts has led to public recognition of their utility by the most senior leaders of several nations.

Broadly, UVS fall into classes defined by their operating environment (air, land and sea), autonomy and size, which in turn defines weight, payload configuration, endurance, mission, etc. They operate in all battlespace environments and are usually referred to as: Unmanned (or Uninhabited) Aerial Vehicles (UAV), Unmanned Maritime Vehicles (UMV)[2] or Unmanned Ground Vehicles (UGV). Their combat variants usually have a "C" inserted between the Unmanned and the environmental descriptor (i.e. "UCAV" for Unmanned Combat Aerial Vehicle).

The military benefits of these systems are proven repeatedly on an almost daily basis with several thousand of them currently in service around the world. The fielded systems provide critical support to operations and comprise a diverse mix of Commercial off the Shelf (COTS) and fielded prototypes that vary in size from a few pounds to tens of tons. They are employed in a range of roles, including rapid environmental assessment (REA), improvised explosive device (IED) detection and defeat, explosive ordnance disposal (EOD), countermining, force protection, obstacle clearance, battle damage assessment (BDA), electronic warfare (EW) and intelligence, surveillance, and reconnaissance (ISR).

There are also a number of key areas of capability where UVS can supplement warfighter activity in ways that they currently do not: logistics, medicine, engineering, security, and maintenance. Similarly, for the foreseeable future most western defence forces will continue to be designed around highly trained, well equipped personnel, selected for their resourcefulness and ability to improvise [13]; but that are dependent upon sophisticated high value assets that act as force multipliers. For survivability, these high-value platforms have historically depended upon sensors and data links to maintain situational awareness, with Electronic Warfare (EW) self-protection often used as a last resort. However, increasingly capable air, land, and sea combat systems now use a combination of sensors networked together to provide an adversary with the capacity to precisely track and target these high value assets at long ranges. As a result, the projection

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[1] Section 220(a) (2) of the Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001 (as enacted into law by Public Law 106–398; 114 Statute 1654A–38), mandates that "It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that

- By 2010, one third of the operational deep-strike force aircraft fleet are unmanned, and
- By 2015, one-third of the operational ground combat vehicles are unmanned."

[2] Comprising Unmanned Underwater Vehicles (UUVs) and Unmanned Surface Vehicles (USVs).

of spectral and physical force in such a way as to have an effect beyond the immediate self-protection of the platforms will almost certainly become vital to the survival of these high value (and likely manned) assets. This is also a role ideally suited to autonomous UVS.[3] Irrespective of their domain or application, the general requirements of UVS are [205]:

- Persistence, low cost, stealth, and ready deploy/retrieve-ability;
- The capacity to detect, locate, track, identify and engage targets autonomously;
- The ability to gather, disseminate and act on several types of information;
- That they are networked together and to the higher-value, manned assets;
- That the individual platform and sensor elements can self-organise; and,
- That they do not impose significant risk or burden upon the operators.

Clearly, application of UVS will not result in ‘bloodless battlefields’ or circumstances in which we ‘press the button and fight the war’ any time soon. Nor will they provide solutions to every capability challenge faced by today’s defence force planners. They will, however, be exploitable in terms of their capacity to carry out dangerous, repetitive and mechanically-oriented tasks currently undertaken routinely by warfighters thereby freeing them for other missions. Furthermore, UVS are particularly well-suited to well-structured and uncluttered environments and tasks and applications where system or mission failure has little or no impact on humans.

In the last few decades while much progress has been made towards these aspirational goals, realisation of the somewhat utopian vision of UVS working persistently and seamlessly together and with manned vehicles in adversarial environments still requires significant scientific advances to be made in a range of areas. As a result we have organised this book into a number of sections:

- The **Background** chapter represents a tapestry of UVS capability from its earliest, faltering steps through to a projection of what is likely within the planning cycles of most defence forces. The objective is simply to provide context for the reader.
- The next chapter, **Autonomous UVS,** describes the functional elements of a UVS, some architectural considerations and human-UVS interaction. The chapter acts as ‘grounding’ for the discussion on the technology, force integration and legal challenges that follow.
- In the chapter on **Technology Challenges** the requirements of next-generation, autonomous UVS operating in dynamic and complex military

[3] Prior to the Global Financial Crisis of 2008-2009, spending on UVS in the US alone was predicted to be in excess of US$33B over the period 2008-2016 (i.e. around US$3.5B annually), with the expenditure profile divided roughly 50%-40%-10% between the procurement, research, and operations and maintenance budgets, respectively [112]. The expenditure on UAVs is expected to dominate with UGVs second (~ US$500m annually) and UMVs rising from about US$20M to US$100M annually over the period. The 2007 Unmanned Systems Roadmap [278], 2009 Unmanned Systems Integrated Roadmap [279] and USAF Unmanned Aircraft Systems Flight Plan 2009-2047 [282], which more than any other recent documents provide an insight into how this money will be spent and what steps will be taken to realise the future potential of UVS, go further than the equivalent documents of other nations by anticipating that fully autonomous swarms of UVS will be achieved by 2015.

environments are considered. The challenges examined pertain more to higher-order tasks such as contextual decision-making, planning and re-planning in dynamic environments, verification and validation, and trust and reliability in human-UVS relationships than to the technological or systems integration challenges that exist for the functional elements of a UVS.

- In **Force Integration** attention is drawn to the fact that the value proposition for many military UVS has yet to be formally quantified. As a result, this chapter discusses some of the challenges for inserting autonomous UVS into existing force structures and presents a methodology that allows them to be assessed in terms of their mission, systems and technological performance based on a range of simulation and assessment techniques.
- In the final chapter on **Legal Issues** the symbiotic relationship between advanced technology, its capability exploitation, and the legal framework in which it must exist is explored. The chapter discusses some of the conundrums that result from UVS having the potential to exercise their own 'judgement' in regard to the lethal prosecution of targets and having to operate in environments shared by people, property and other vehicles.

Many of these challenges are equally applicable to commercial or non-military unmanned vehicle systems. For example, irrespective of application – and regardless of whether this is commercial or military – the payload-mission combination defines the overall system requirements. This does not usually impact the key functional elements of the system, which inevitably include mobility, localisation, navigation, and planning, irrespective of the mission. Furthermore, a degree of 'cognitive' or higher level planning capability relative to task complexity often translates to mission flexibility. In this book, the challenges are interpreted solely in terms of military missions, and their interpretation in the context of commercial application is left as an exercise for the reader.

Similarly, it is also recognised that both commercial and military vehicles will ultimately occupy environments shared by other users, which will in turn require them to obey the established 'rules of the road.' However, even though such technology and legal challenges are equally relevant to both military and commercial users and applications, they are not explicitly discussed in this book in the context of the many potential commercial uses. Additionally, even though a number of advances in military automation and unmanned systems are likely to extend beyond the commercial applications into the area of manned transport,[4] these 'dual use' technology issues are identified and discussed solely in terms of their suitability to military unmanned systems.

[4] For example, technologies that allow UAVs to detect, see, and avoid other aircraft are likely to benefit pilots of manned aircraft who are otherwise occupied or have heavy workloads. Similarly, while it is technically feasible for manned aircraft to be flown for short periods in nuclear, biological or chemical contaminated environments and to protect pilots from the blinding effects of high powered lasers, technologies that allow such aircraft to operate in such adverse environments and land safely after such exposures are inherently advantageous (lasers that have the potential to blind pilots are considered illegal, but so long as there are adversaries that do not respect the Laws of Armed Conflict such weapons remain a potential threat to manned aviation).