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UAVs/UCAVs – MISSIONS, CHALLENGES, AND STRATEGIC IMPLICATIONS FOR SMALL AND MEDIUM POWERS

Manjeet Singh Pardesi

Institute of Defence and Strategic Studies
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ABSTRACT

Unmanned Aerial Vehicles (armed and unarmed) are playing a crucial role in defense transformation by providing the military with a new platform that exploits advances in info-communications technologies, while playing a crucial role in the network-centric warfare concept. This paper studies various air missions (Intelligence, Surveillance, and Reconnaissance, Suppression of Enemy Air Defenses, Counterair etc.) to determine whether the UAVs represent a truly disruptive technology. This paper also studies the strategic implications of UAVs for small and medium powers. It concludes that the UAV is not a truly disruptive technology as there will always be missions that will require the manned aircraft. Their software complexity, automation and communications architecture makes them operationally unreliable for many missions and also considerably increases their cost by making them nearly as expensive as their manned counterpart. Advances in air defense systems and manned counterair aircraft considerably limit the utility of the unmanned platform for many air missions. This research concludes that the future is likely to see a mix of manned and unmanned aircraft networked with satellites performing complex air missions. The research also concludes that small and medium powers are likely to find UAVs useful in ISR roles only as the unmanned combat platform is still an unproven technology and is in its developmental stages. However, collaboration, licensed production, and joint marketing are areas that will allow small and medium powers (together perhaps with the United States) to come together for a joint effort.

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BIOGRAPHY

Manjeet Singh Pardesi has been an Associate Research Fellow (Revolution in Military Affairs Programme) at the Institute of Defence and Strategic Studies, Singapore, since August 2003. He was initially trained as an Electrical and Electronic Engineer at the Nanyang Technological University, Singapore, where he studied on a Singapore Airlines/Neptune Orient Lines Scholarship. Thereafter, he pursued an MSc in Strategic Studies on a Singapore Technologies Engineering Scholarship at the Institute of Defence and Strategic Studies, Singapore. His research interests include Defence Technology (especially emerging technological trends and their potential for an RMA), the role of weapons of mass destruction in the 21st century, great power politics and India’s foreign and security policy with an emphasis on Indo-US, Indo-China and India-ASEAN relations.
UAVs/UCAVs – MISSIONS, CHALLENGES, AND STRATEGIC IMPLICATIONS
FOR SMALL AND MEDIUM POWERS

Victory smiles upon those who anticipate the changes in the character of war, not upon those who wait to adapt themselves after the changes occur.

Giulio Douhet

1. INTRODUCTION

The absorption of modern info-communications technologies (ICTs) has transformed the US military. This transformation has in turn changed the conduct of warfare in two ways – by enhancing platforms and by enabling network-centric warfare. Unmanned Aerial Vehicles (UAVs), armed and unarmed, are playing a crucial role in this revolution, as they provide the military with a new platform that exploits the advances in ICTs, and at the same time are integral to the network-centric warfare concept. Although interest in UAVs is as old as the history of manned aviation, UAVs started making news due to their military effectiveness in recent conflicts such as Iraq (2003) and Afghanistan (2001). The Afghanistan campaign highlighted the growing role of UAVs, because it was in Afghanistan that the UAVs actually started attacking targets in addition to performing their primary mission of intelligence gathering and guiding weapons to their target.  

This paper seeks to question whether the UAVs represent a truly disruptive technology. What will be the impact of UAVs on manned aircraft and how does the increased use of unmanned platforms alter the strategic landscape? To this end, this paper will examine various air operations – Intelligence, Surveillance, and Reconnaissance (ISR), Suppression of Enemy Air Defenses (SEAD), Counterair etc. – to establish the transformative impact of UAVs, if any. This research will also briefly discuss how Mini/Micro Aerial Vehicles (MAVs), which are a subset of UAVs are likely to be deployed on the battlefield. Additionally, this paper will analyze the US Department of Defense (DoD) commitment to

UAVs through an assessment of its budgetary investments in UAVs compared to manned systems. This paper will go on to highlight the strategic implications of UAVs for small and medium powers. It will highlight the missions that are likely to be transformed with the introduction of UAVs and make a policy recommendation to these states with limited defense (and R&D) resources to invest only in these mission areas.

2. HISTORY

The US DoD defines an unmanned aerial vehicle as, “A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semiballistic vehicles, cruise missiles, and artillery projectiles are not considered unmanned aerial vehicles.”² While the idea of removing the pilot from the cockpit may be conceptually simple – the UAV presents an operational challenge, as it is a system designed to fly in a hostile environment. Conventional wisdom states that removing the pilot from the aircraft would mean that the extensive and expensive life-support equipment is not needed, thereby making the UAV more cost-effective. UAVs vary in size from systems that can be held in the palm of the hand to systems the size of commercial jet aircraft.

Even though the UAV concept seems somewhat revolutionary in nature, it is not new. Starting with the kite, the Chinese sought to achieve military advantage with devices held aloft by aerodynamic forces, as early as third century BC.³ In Europe, kites were first used for military purposes in the Battle of Hastings in 1066.⁴ The Americans first used unmanned aviation in combat when journalist William Eddy took hundreds of photographs during the Spanish-American War in 1898 from cameras suspended from a kite.⁵ The first heavier than air, sustained, powered flight was achieved by a pilotless aircraft when Dr Samuel Pierpoint

⁴ Ibid., p.655.
⁵ Ibid., p.656.
Langley launched his steam-powered aircraft over the Potomac River on May 06, 1896, for a flight lasting for over one minute. After the Wright brothers first piloted, powered flight on December 17, 1903, unmanned aviation took a backseat compared to manned aviation.

During World War I, the US decided to make a contribution in the novel area of the flying bomb (known as cruise missile today). As a result of technological immaturity and a declining defense budget after the war, the US scrapped the project in 1922. The most important development for unmanned aviation during the interwar years was radio control. World War II saw the US Army Air Forces remotely control an aircraft under a program code-name Aphrodite. The program was suspended, as none of the Aphrodite bombers were successful. Post-World War II, the Ryan Aeronautical Company successfully developed two types of target drones – Q-1 and Q-2.

In 1960, a U-2 reconnaissance plane piloted by Francis Gary Powers was shot down over Russia. This was followed by another American loss when an RB-47 on an electronic intelligence-gathering mission over the Barents Sea was shot down. Under great urgency, the US Air Force awarded Ryan Aeronautical two highly classified contracts code-named Red Wagon and Lucy Lee to demonstrate its drones for photo-reconnaissance missions. However, due to spiraling costs, both programs were terminated. Two years later, in 1963, under a procurement concept called Big Safari, the US met its first success for unmanned reconnaissance aircraft. This led to the birth of Ryan 147 Lightning Bug, which flew a total of 3,435 operational reconnaissance UAV sorties during the Vietnam War between 1964 and 1975. In 1971, the US demonstrated a historic first missile launch from a drone when the Lightning Bug modified BGM-34A was used to fire a guided air-to-surface missile against a

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7 UAVs and cruise missiles use related technology, however, the main difference between the two is that while the UAV is a reusable system, the cruise missile is not.
9 The most important unmanned systems to be used during the Second World War were V-1 and V-2 rockets. However, these were the precursors to modern day Intercontinental Ballistic Missiles, not UAVs.
10 Clark, op. cit., pp. 10-11.
11 Ibid., p. 12.
13 Ibid., pp. 13-20.
simulated SAM (surface-to-air missile) site. It achieved a direct hit. Since this system was still under development, the first Unmanned Combat Aerial Vehicle (UCAV) played no part in the Vietnam conflict. After the war, by 1979, the various UAV/UCAV programs were shelved or canceled due to cuts in the defense budget.

Israel’s successful use of UAVs during operations in Lebanon in 1982 rekindled American interest in this system. US navy acquired the Pioneer UAV from Israel, which provided tactical level intelligence during Operation Desert Storm in 1991. The ineffectiveness of the Tomahawk Land-Attack Missile (TLAM) attacks on Osama bin Laden’s camps in Afghanistan, in retaliation for al-Qaeda sponsored US embassy bombings in Africa in August 1998 generated military interest in new roles for armed and unarmed UAVs. During Operation Allied Force, UAVs performed numerous functions that included target identification, probing of Serbian air defenses, monitoring ethnic cleansing, bomb damage assessment, electronic intelligence operations, airborne communication relays and jamming of Serbian communications.

In Afghanistan, the Predator UAV started performing ‘armed reconnaissance’ as mentioned earlier and the Global Hawk UAV made its debut in the skies over Afghanistan in 2001, even though it was an experimental system then. In the recent Operation Iraqi Freedom, Global Hawk UAVs provided imagery of Iraqi Republican Guard divisions. The Predators continued their combat role by attacking high value targets in Iraq. Surveillance UAVs also helped US Special Forces in preventing Iraqis from launching any hidden Scud missiles.

3. ROLES AND MISSIONS

14 Ibid., pp. 23.
16 Ibid.
20 Krepinevich, op. cit.
While there is a good deal of confidence in the underpinning technology of unmanned platforms, there is a great deal less certainty surrounding their roles and missions. UAVs/UCAVs are likely to play a key role in mission areas commonly categorized as “the dull, the dirty and the dangerous”. This section discusses some of the more important air missions (ISR, strike/SEAD, and Counterair) to determine if UAVs/UCAVs can replace manned platforms in some or all of these roles. This will be followed by a short analysis on the role of MAVs on the battlefield. It must be pointed out that the move towards unmanned platforms is not necessarily due to the inadequacy of manned aircraft. Rapid technological advancement over the past decade has led to a “technological push” in this direction. Moreover, since the end of the Cold War, the US has been attempting to replace manpower with technology, mostly because it retains strategic interests in every corner of the globe but is increasingly hesitant to commit its military personnel for several of these missions. The move towards the unmanned platform is a result of all these developments.

3.1 Intelligence, Surveillance, and Reconnaissance (ISR)

UAVs have been traditionally used as Intelligence, Surveillance, and Reconnaissance (ISR) assets, and their ability to do so is being boosted by the advances in sensor and modern information-communications technologies. For the US, ISR collection is a critical factor in achieving the Joint Vision 2020 operational concept of ‘precision engagement’. During the Vietnam War, the photos provided by the Ryan 147 Lightning Bug revealed precise locations of SAM sites, enemy airfields, ship activity in Haiphong Harbor and battle damage assessment (BDA) provided intelligence that otherwise would have been obtained only if manned aircraft were sent in harm’s way. In Operation Desert Storm, the Pioneer UAV contributed to the tactical successes of the US Navy and Army by playing an important role in target designation, damage assessment and reconnaissance.

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23 Clark, op. cit., pp.15-16.

24 Clark, op. cit., pp.34-35.
In Afghanistan, Global Hawk was used for reconnaissance prior to the strikes and for post-strike BDA.\(^\text{25}\) The Predator was used in Afghanistan to feed imagery to AC-130 special operation gunships and special operations teams on the ground.\(^\text{26}\) Global Hawk accounted for only 5 per cent of intelligence sorties during Operation Iraqi Freedom but produced 50 per cent of the information on time-sensitive targets.\(^\text{27}\) It is important to note that unmanned aerial vehicles retreated to their traditional role of reconnaissance in Iraq in spite of some successes in combat role in Afghanistan. In Afghanistan, barely a dozen UAVs launched 115 Hellfire missiles and laser-designated 525 targets. But in Iraq, where more than 56 larger UAVs and more than 60 smaller portable ones were used, UAVs launched only 62 Hellfires and designated only 146 targets. The main reasons were Iraqi winds and sandstorms (and the fact that these aircraft are much lighter than their manned counterpart) and the increased need for intelligence in the Iraqi campaign.\(^\text{28}\) The growth of asymmetric warfare highlights the importance of unmanned ISR platforms.

UAVs face two competing systems for performing ISR missions – manned platforms and satellites. While providing a significant improvement in information collection capability over these competing systems, UAVs also pose some serious limitations.

Being large and manned aircraft, AWACS (Airborne Warning and Control System) and JSTARS (Joint Surveillance Target Attack Radar System) have limited maneuverability and self-defense. Unlike the loss of UAVs, loss of these expensive manned systems is likely to cause severe domestic political repercussions for the US. However, given the current state of technology, UAVs cannot completely replace AWACS and JSTARS manned aircraft in ISR missions. Advanced sensor technology is still under development and IT is not sufficiently developed to perform the battle management and command and control functions handled by AWACS and JSTARS personnel. The military is seeking sensors with high definition television (HDTV) standards\(^\text{29}\), foliage penetration radar (FOPEN) with hyperspectral imagery, synthetic aperture radar (SAR) and moving target indication (MTI) mode to track


\(^{26}\) Bone and Bolkom, op. cit., p.14.


\(^{29}\) Predator is a medium altitude UAV that transmits video signals. To gain better situational awareness in the future, UAVs will need to fly higher. Higher altitude degrades video signals; hence migration to commercial HDTV standards is essential.
targets in all types of terrain throughout the spectrum of military operations. Due to their inability to absorb data and reason (at least for the foreseeable future), UAVs cannot process and relay the same amount of data as a pilot in the cockpit (who can do so by learning, experiencing, and by intuition) and cannot maintain a 360-degree situational awareness (SA).

Manned missions provide high resolution data and are extremely flexible at adapting to multiple mission scenarios, however, their main limitation is their loiter time. UAVs on the other hand are capable of long loiter times; are smaller and hence stealthier than manned platforms; much less costly to procure, operate, and support; and avoid putting pilots at risk. However, fast jet-based tactical reconnaissance remains a much sought after, but scarce capability for UAVs. The use of Global Hawk, Predator and JSTARS systems (i.e., both manned and unmanned platforms) was the key factor behind the shattering of the Republican Guard and the success of the SCUD suppression campaign in western Iraq during Operation Iraqi Freedom. It is possible that in the future UAVs will be faster and more maneuverable, but it must be remembered that higher speed creates penalties for loiter time, one of the biggest assets of unmanned platforms.

UAVs have a major advantage over satellites in addition to being cheaper as it is easier to alter their flight paths and coverage. Moreover, they provide a comparatively cost-effective method of collecting ISR. UAVs also have an additional advantage of being able to fly closer to the target. Operation Desert Storm highlighted the pivotal role that satellites will have in future conflicts, as space (due to the salience of satellites) became an area of strategic significance. However, the major drawback with UAVs as mentioned above is their lack of situational awareness. This shortcoming can be overcome by integrating UAVs with reconnaissance satellites. However, high data rates (bandwidths) are essential for real-time interactive command and control systems like flight controls, video reception and transmissions. UAVs are major consumers of bandwidth. Since September 11, 2001, the

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31 A predator is a slow platform that takes 30 minutes to travel 50 nautical miles. UAVs offer a trade-off between speed and loiter time.
32 Donnelly and Vickers, op. cit.
34 A video image of 300 by 300 pixels, and eight bits per pixel takes 720 kilobits to encode in a single frame. For smooth, continuous perception by a human operator this information needs to be refreshed at a rate of no
need has increased eight-fold due to the war in Afghanistan and the pursuit of terrorists in the region.\textsuperscript{35} Stationing the mission control on a standoff aircraft (within line-of-sight) would decrease the dependency on satellites generated by stationing the mission control on the ground thousands of miles away. More autonomous UAVs will also require less bandwidth as more data will be processed on board.\textsuperscript{36} It should also be remembered that since the UAVs fly in close proximity to the target, they would need to have a high signal-to-noise ratio (especially if they are flying far from their control station), thus increasing their possibility of detection.

The way forward is to integrate manned, unmanned, and satellite-based sensors to create a common operational picture of the battlefield. However, the spread of unintegrated information can be disastrous in a military campaign. Development of ICTs and software algorithms to fuse the data provided by the three platforms will be crucial to ISR operations in the future. A successful ISR mission must have a reliable, robust, secure and high-capacity communications infrastructure. The information collection system of the future is likely to be based on space-based assets providing wide area surveillance at a low level of resolution, but looking for cues that require detailed monitoring. This detailed monitoring will be performed by manned and unmanned vehicles.

\textbf{3.2 Suppression of Enemy Air Defenses/Strike}

US military strategy post embassy bombings in Africa focused on targeting Osama bin Laden and his training camps with TLAMs. This strategy did keep US troops out of harm, but it suffered from many operational limitations, the most important being the long delay between acquiring reliable intelligence on the precise location of time-sensitive targets (from the skies over Afghanistan) and the execution of an actual cruise missile attack (from ships in the

\textsuperscript{35} Bone and Bolkcom, op. cit., pp. 17-18.

\textsuperscript{36} Bone and Bolkcom, op. cit., pp. 17-18. The Global Hawk is an autonomous rather than a remotely piloted vehicle. In spite of this, the UAV still requires multiple satellite and line-of-sight links for control, inflight mission re-routings, and the relay of sensor data.
Arabian Sea). The US was looking for an ‘armed reconnaissance’ platform to strike time-sensitive targets. Technological momentum led the US Air Force to fit two 45-kg, laser guided Hellfire-C missiles to the Predator UAV. On 15 November 2001, two Hellfire missiles launched from a Predator killed Muhammad Atif, al-Qaeda’s chief of military operations. This was the first use of the Predator as a weapons platform. In another highly publicized event almost a year later, on 3 November 2002, a CIA-operated armed Predator flying over Yemen, with Yemen’s approval, killed a top al-Qaeda operative, Ali Qaed Sinan al-Harthi, and his five companions traveling in the same car. By performing successful “strike” missions, these incidents demonstrated the usefulness of armed UAVs in the global war against terrorism. These strike missions opened up a new debate on a possible new role for the armed UAVs – Suppression of Enemy Air Defenses (SEAD).

The US DoD defines SEAD as an “activity which neutralizes, destroys, or temporarily degrades surface-based enemy air defenses by destructive and/or disruptive means.” The Predator UAV was credited with two strikes in Operation Iraqi Freedom in March 2003 – one strike was against an anti-aircraft vehicle while the other was against a TV satellite dish in Baghdad. The US is currently developing a new version of the armed Predator UAV, called Predator B, which will have the capability to carry eight Hellfire missiles instead of two. The US is also developing newer platforms – UCAVs – that are being developed with a primary offensive mission of strike and SEAD.

To determine the efficacy of the unmanned platform in a SEAD role, the US will need to consider two rival challenges – the adoption of new counter-tactics by its opponents, and the development of new anti-air systems.

Today, the US relies exclusively on the F-16 and the Navy’s EA-6B for defense suppression missions. The loss of a modern, expensive platform like the F-16 (and its pilot) will be a major political embarrassment for the US, in addition to being an economic loss. SEAD is an

38 Ibid., p. 417.
39 Ibid., p. 417.
important mission as it helps in attaining ‘air superiority’. The air forces can attack the heart of the enemy (i.e., perform the ‘interdiction’ mission) only after gaining command of the air. However, during Operation Desert Storm, the super-stealthy F-117 allowed the US to engage in ‘parallel warfare’\textsuperscript{43}, i.e., it freed the US from rolling back enemy air defenses and enabled the F-117 aircraft to hit the heart of the enemy within the opening minutes of the conflict.\textsuperscript{44} However, the Serbs learned from this conflict and adopted a “shoot and scoot” tactic by not deploying a determined air defense system. This enabled them to launch 700 missiles in the course of the 78-day conflict and caused enormous frustration to the US airmen.\textsuperscript{45}

In addition to such tactics, the US is also likely to face “anti-access threat systems” like SAMs, cruise missiles, theater ballistic missiles, and other advanced air defense systems. The range of modern SAMs (estimated to be between 50 and 250 miles), is forcing the US to develop strategies and systems to reduce the risk to its airmen.\textsuperscript{46} It must be highlighted that missiles launched from a distance from mobile SAM sites are difficult to detect, and that the high speed of newer missiles makes them more maneuverable.\textsuperscript{47} This means that the friendly aircraft/UAVs will have a very narrow “escape zone” to avoid the SAMs. Unmanned jet engine G force limitations (±12G) do not significantly exceed those of the human pilot (between –3G and +9G) and hence do not substantially increase defensive capability against missiles.\textsuperscript{48} It must be pointed out that the cost arithmetic further complicates the analysis and is not useful in determining the efficacy of UCAVs over current standoff systems like cruise missiles.\textsuperscript{49} JDAMs employed by UCAVs may be cheap compared to the Tomahawk, but the

\textsuperscript{43} ‘Parallel warfare’ is a non-linear war-fighting technique. In traditional ‘series warfare’, target sets are attacked in a linear sequence in a progressive march on to the enemy’s nerve centers.


\textsuperscript{46} Countering “anti-access” threats implies a capability to operate from well outside an enemy’s defenses. See John A Tirpak, “The Double Digit SAMs”, Air Force Magazine, June 2001. Countries as diverse as China, Iran, Ukraine, Russia, and Croatia possess the Russian built double-digit S-300 SAMs.

\textsuperscript{47} Most SAMs are faster than High-Speed Anti-Radiation Missiles (HARMs).

\textsuperscript{48} Seated human beings lose consciousness if subjected to maneuvers harder than –3G or +10G. Nevertheless airframes and mechanical components can be designed to operate out to the ±20G envelope. See David Bookstaber. Unmanned Aerial Combat Vehicles – What men do in aircraft and why machines can do it better [Online]. Available: www.airpower.maxwell.af.mil/airchronicles/cc/ucav.pdf [2003, December 11]. Designing jet engines that could withstand 20Gs would require billions of dollars in development or would produce limited thrust-to-weight ratios (speed). Moreover, even if the engine technology allows the vehicle to withstand high G forces, the sensor technology is unlikely to allow the vehicle to maneuver in the proper direction at the proper time. See Ehrhard, op. cit., p. 574.

\textsuperscript{49} Joint Direct Attack Munitions (JDAMs) employed by UCAVs have a unit cost of $21,000 compared to $600,000 for a Tomahawk cruise missile. This cost-per-kill contrast will favor UCAV use in many instances. See Col Robert E Chapman II, “Unmanned Combat Aerial Vehicles – Dawn of a New Age?”, Aerospace Power
UCAV, which is an expensive recoverable platform, is likely to suffer considerable attrition due to its proximity to the target.

It must be noted that UAVs/UCAVs will play an important role in electronic attack missions, however, they will at best play a limited role only as the future use of Electromagnetic Pulse (EMP) weapons and Directed Energy (DE) weapons will increase the risk of self-jamming for the unmanned platform itself. The new S-400 SAM system with a range in excess of 250 miles would also render manned standoff jamming platforms useless.\(^\text{50}\)

It makes sense to use low-cost UAVs and/or decoys to locate the positions of the SAM sites, which may be then be attacked as a part of a ‘reactive’ SEAD strategy. This together with UCAVs equipped with passive sensors (an extremely stealthy platform), represents an effective counter to mobile defenses. There are however, several constraints here that must be kept in mind – (1) the primitive nature of current target recognition programs means that a human operator must be kept in the loop to authorize the ‘kill’\(^\text{51}\), thereby, increasing the bandwidth requirements\(^\text{52}\), and (2) integration with other ISR platforms is necessary to locate time sensitive targets.\(^\text{53}\) These constraints put serious limitations on the use of unmanned combat platforms in ‘reactive’ SEAD missions. UCAVs are more likely to play an important role in ‘pre-emptive’ SEAD missions (where the exact locations of enemy SAM sites are known) as opposed to ‘reactive’ SEAD missions.\(^\text{54}\) UCAVs, integrated with manned and unmanned assets like AWACS, F-16s, F-117s, Global Hawk, and communications satellites will play a role in future SEAD missions (reducing some risk to manned assets in this high threat environment), however, they will be one of many ‘arrows in a quiver’, and not a ‘silver
bullet’. UAVs/UCAVs are nevertheless very suitable for strike missions, especially against a very heavily defended target due to their high level of stealth.

### 3.3 Counterair

In March 2003, Predator launched a Stinger air-to-air missile at an Iraqi MiG before the Iraqi aircraft shot it down.\(^5\) This has led to the speculation that armed UAVs/UCAVs will play a role in counterair operations (and by extension as air superiority fighters in the future). The US DoD defines counterair as “a mission that integrates offensive and defensive operations to attain and maintain a desired degree of air superiority. Counterair missions are designed to destroy or negate enemy aircraft and missiles, both before and after launch,”\(^5\) and defines air superiority as “that degree of dominance in the air battle of one force over another that permits the conduct of operations by the former and its related land, sea, and air forces at a given time and place without prohibitive interference by the opposing force.”\(^5\)

During Operation Desert Storm, coalition forces flew over 13,000 counterair missions, averaging 340 sorties daily, thus ensuring air superiority. The USAF F-15C, USN F-14A/D, and USN and USMC F/A-18 aircraft were the platforms instrumental in the command of the skies over Iraq.\(^5\) The same air assets were available during Operation Allied Force for the function of counterair. Lockheed Martin’s F-22 Raptor is likely to play the key role in America’s air superiority efforts in the years ahead.\(^5\) Stealth, maneuverability, and cost are the most important design pre-requisites for air superiority fighters of the future.\(^6\) Whether or not a UCAV will replace the F-22 fighter (a manned platform) is a crucial question as American air superiority in a future conflict depends on the answer to this question. This is also a timely question since the decisions taken today will guide the research, development, production, and training of the new system (manned or unmanned replacement of the F-22

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\(^9\) Stealth enhances survivability before engagement and maneuverability enhances survival while engaged.
fighter) over the next two decades (a period at the end of which the F-22 will most likely retire). Aerial combat is the most challenging mission for manned aircraft to perform and it is believed that missiles do not always kill the adversary (especially one equipped with significant counterair assets and capabilities like the MiG-29 Fulcrum and the Su-27 Flanker⁶¹), so close engagements are necessary.⁶² Combat survivability remains the most significant limitation to UAV employment.⁶³ It has been mentioned in sections 3.1 and 3.2 that limitations imposed by line-of-sight data transfer requirements will enhance the role of satellite communications. However, the current American and allied satellite communications infrastructure is incapable of supporting any sizable number of UAVs or UCAVs. Global Hawk consumed five times the total bandwidth used by the entire US military in the Gulf.⁶⁴ Autonomous systems will reduce bandwidth requirements, however, it is unlikely that the UCAV will replace the manned aircraft in all operations as some politically sensitive targets will still need a human operator to make the “kill decision”. Moreover, cognitive systems based on artificial intelligence (AI) are unlikely to replace the human completely, even though significant developments are likely to occur over the next two decades.

Stealth requirements dictate that the UCAV weapons be small and by extension, precise. The weaponization of the unmanned platform for air superiority missions is not likely to happen over the next two decades.⁶⁵ In the near future, the UCAV is not likely to have its own air-to-air weapons and is going to carry weapons like the Sidewinder missile and AMRAAM that already exist.⁶⁶ UAVs/UCAVs will be used predominantly to provide active sensors against highly lethal anti-aircraft weapons in support of inhabited vehicles.⁶⁷ UCAVs are unlikely to replace the manned aircraft for air combat missions in the policy relevant future. The future

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⁶¹ Other advanced air superiority fighters under development include the MiG 1.44MFI, the S-37 Berkut, and the Chinese built J-10 and J-12 aircraft. The proliferation of advanced S-300 and S-400 integrated air defense systems is also a serious concern for the Americans. Ballistic Missiles also pose a significant threat.

⁶² The F-22 has been optimized for close air-to-air combat.

⁶³ The low altitude of tactical UAVs makes them susceptible to small arms fire. Strategic UAVs fly higher but at speeds observable by radar. Moreover, they may be within the range of modern SAMs. See Major Ronald L Banks, “The Integration of Unmanned Aerial Vehicles into the Function of Counterair” (Master’s dissertation, Air Command and Staff College, Air University, Maxwell Air Force Base, Alabama, US, 2000), p. 18.


⁶⁵ Lewis, op. cit., p. 50. The small Stinger missile has minimal capability against manned aircraft and is a threat to friendly UAVs and helicopters. Directed energy weapons and lasers are ideal for use with UCAVs. However, initially they will require huge amount of power and will be too large to fit even on large commercial aircraft.

⁶⁶ Lewis, op. cit., p. 52.

⁶⁷ Manned platforms will mostly rely on passive sensors.
will see a mix of manned and unmanned platforms together with space weapons in counterair operations.

### 3.4 Mini/Micro-Aerial Vehicles

The United States is also heavily investing in a new class of unmanned platforms – Mini/Micro Aerial Vehicles (MAVs). MAVs are a subset of UAVs that are roughly two orders of magnitude smaller than manned systems (some as small as 6-inches). These compact lightweight air vehicles carrying miniature sensors play a key role in the war against terrorism. While MAVs are more vulnerable to attack and loss due to their low altitude, this is compensated by the fact that they are extremely stealthy and very cheap. Their compact size and low weight will allow them to be carried by individual soldiers. The US Air Force is deploying MAVs for force protection in the shape of Lockheed Martin SentryEye.

MAVs have tremendous potential for ISR operations. In the battlefield, they are likely to be operated by individual soldiers for local reconnaissance. MAVs integrated with a high-flying UAV will circumvent the need to develop foliage penetration sensors. They will also play an important role in urban operations where stealthy airborne assets closer to the ground may be required. In the sea, MAVs can also be deployed from ships to gather intelligence in order to prevent acts of maritime terrorism. They may also be fielded in a hostile environment to detect people with shoulder-fired missiles to attack aircraft. MAVs shall play an important role in real-time detection and analysis of a biological or a chemical agent in an infected environment. They are also likely to play an important role in humanitarian missions, e.g. searching for survivors amidst rubble from earthquakes.

Swarms of MAVs equipped with sensors and miniaturized warheads are theoretically capable of attacking high-value targets such as radars and launchers of SAM sites, i.e., they are likely to play an important role in SEAD missions in the future. Global Positioning System (GPS) allows precise autonomous navigation and position reporting for MAVs, which are critical to

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69 Hewish, *Small, but well equipped*, op. cit.

70 Ibid.
the military application of these technologies. Some of the limitations of this technology are its small range and high damage potential (especially due to the prevailing weather). Microelectromechanical systems (MEMS), micro-manufacturing and nanotechnology could provide an exponential leap in microminiaturization for weapons, sensors and platforms.\textsuperscript{71}

4. FISCAL CHALLENGES

The US DoD is planning on investing around $10 billion in UAVs in the first decade of this century and plans to quadruple today’s 90-aircraft inventory by then.\textsuperscript{72} This invites comparison with the fact that the US Air Force has spent close to $20 billion on the F-22 air superiority fighter which will cost at least $100 million per aircraft to produce and will purchase close to 300 F-22s.\textsuperscript{73} The US will also spend between $28 million to $38 million per aircraft on a new tactical fighter called the Joint Strike Fighter (JSF) and with the intention to purchase up to as many as 3,000 JSFs.\textsuperscript{74} The total system cost of the Predator UAV, which is about $28.3 million, is about the same as a single seat F-16A.\textsuperscript{75} Although the unmanned platform might be cheaper than its manned counterpart,\textsuperscript{76} the UAV system on the whole is not always less expensive. Besides, it is estimated that the DARPA/Boeing X-45 UCAV will cost about $25 million (per unit).\textsuperscript{77}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
Manned/Unmanned System & Cost \\
\hline
F-22 Raptor (per unit) & US$100 million \\
JSF (per unit) & US$28-38 million (depending upon specs.) \\
Predator System & ~US$28 million \\
X-45 UCAV (per unit) & ~US$25 million \\
\hline
\end{tabular}
\caption{Approximate costs of current and future manned and unmanned air platforms}
\end{table}

\textsuperscript{71} For the potential military applications of MAVs, see Timothy Coffey and John A Montgomery, “The Emergence of Mini UAVs for Military Applications”, \textit{Defense Horizons}, December 2002.
\textsuperscript{72} David A Fulgham, “Pentagon Eyes Quadrupling UAV Force by 2010”, \textit{Aviation Week & Space Technology}, 17 February 2003.
\textsuperscript{74} Ibid.
\textsuperscript{75} Lt Jeff Mustin. (2001). \textit{Flesh and Blood: The Call for the Pilot in the Cockpit} [Online]. Available: \url{http://www.airpower.maxwell.af.mil/airchronicles/cgo/mustin.html} [2003, December 26]. It is important to think of UAVs/UCAVs as part of a system comprising the unmanned air vehicles (typically one to six), the sensor-shooter package, the control station (on ground or in the air), communications architecture, and other support equipment.
\textsuperscript{76} A Predator UAV (single unit) costs around $4 million.
\textsuperscript{77} Sweetman, op.cit., \textit{UCAVs grow fat on requirements}. 

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It is clear from Table 1 that the unmanned platform does not necessarily offer the cost-effectiveness that it promises. Unmanned systems are “attributable”, but not expendable, i.e., it is fine to lose them when the alternative to their loss is the manned aircraft. Expendability is not an option since these are not cheap systems. In addition, for the unmanned platform to replace the manned fighter, it must offer the same level of reliability as the manned platform (or exceed it). It should also be highlighted that UAVs are on average lost at a much higher rate than manned aircraft.\textsuperscript{78} DARPA, Boeing, and the US military are working together to develop a pure UCAV called the X-45 and its naval version UCAV-N, which are likely to play a major role in strike missions and electronic attacks in the future. These systems are likely to become operational in the 2008-2015 timeframe.\textsuperscript{79,80} Nevertheless, it is important to remember that these systems are still under development and would need to undergo extensive testing to prove their technological capability. Unless they are tried and tested in an actual operation (in small numbers at first), these systems are unlikely to challenge the manned platform in any significant way.

5. STRATEGIC IMPLICATIONS FOR SMALL AND MEDIUM POWERS

On the one hand, UAVs enable the United States to intervene militarily anywhere in the world whenever its interests are threatened (whether through ISR missions or in a combat capacity through surgical strikes, pre-emptive SEAD missions etc.) without putting its forces in harm’s way. On the other hand, this possibility will drive certain nations to acquire armed UAVs and/or weapons of mass destruction (WMD) to oppose a US led intervention.\textsuperscript{81,82} It

\textsuperscript{78} Predator cannot be launched in adverse weather including visible moisture. Moreover, a large number of crashes are due to human operator error. The crash rate of a Predator is an order of magnitude higher than the F-16. This rate will not be acceptable for multi-million dollar UCAV that costs as much as a manned fighter. See Sweetman, \textit{UAVs Grow Fat on Requirements}.


\textsuperscript{81} At least 40 countries have produced more than 600 different types of UAVs, many with ranges in excess of 300km. See Gormley, op. cit., p. 410.

\textsuperscript{82} This notwithstanding, it is important for the strategic studies literature to study the implications of battlefield automation (especially societal implications from a moral perspective). Will the nature of war itself change when both belligerents fight with unmanned platforms, as this development is likely to change war into an economic transaction (an expensive video game) by removing the human from the equation? Unmanned technology is likely to give offensive forces a distinct advantage over defense. Will this increase the propensity for the belligerent equipped with unmanned platforms to attack its enemy especially if its enemy lacks these
must be emphasized that the greatest risk is posed by terrorist use of armed UAVs. In the US missile defense system (especially those in the boost phase), UAVs are also likely to play an important role as interceptors to destroy ballistic missiles. The proliferation of armed UAVs in the arsenals of its opponents is nonetheless going to complicate the cost-per-kill arithmetic for US missile defenses. UAVs will also enable regional powers to bolster their power projection capabilities. India has raised its profile in the Indian Ocean Region by operationalizing its first full-fledged UAV base in Kochi where its Southern Naval Command is based. India also plans to set up UAV bases in Port Blair in the Andamans and Lakshadweep islands.

What lessons should small and medium powers draw from the current and projected technological challenges and operational capabilities of UAVs/UCAVs? The extent to which small and medium powers can absorb high technology into their militaries depends on various factors. Singapore, with its well-educated workforce, knowledge-based economy, a sophisticated defense-industrial base, political stability and extensive ties with Western companies is well placed to absorb advanced technologies into its military forces.

It is in ISR missions where the use of UAVs is the most promising and it is precisely here where small and medium powers are advised to spend their resources and perhaps experiment with arming their UAVs. ISR capability will enable these states to gain “dominant battlespace knowledge” in a conflict, and their homeland security is further boosted when combined with an “armed reconnaissance” capability. They must bear in mind though that just developing these technologies is not enough; their successful integration into the services is an equally daunting and time-consuming task. In addition to this, technological challenges especially bandwidth requirements and systems integration pose considerable hurdles. These states will need to invest in satellite technology to solve the bandwidth

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83 An unmanned aircraft’s flight stability permits the effective release of biological agents along a line of contamination. Ibid., p. 413.
84,1462 [2004, February 20].
85 A Patriot PAC-3 missile costs $2-5 million compared to $50,000 for an aircraft adapted to become an armed UAV. Ibid., p. 411.
87 An important impediment to UAV integration is their operation by groups with minimal aviation expertise. Up to 20% of UAV losses are due to human error. See Bone and Bolkcom, op. cit., p.13.
limitation. UAVs are also likely to have numerous commercial applications that will interest small and medium powers, e.g., in telecommunications networks as relays, for crop spraying etc. This is good news for the defense sector, as it is likely that some of the research on unmanned technologies will be carried out by the commercial/university sector. Furthermore, many of the technologies involved (autopilot systems, satellite navigation and guidance systems, digital mapping technologies for mission planning, and collision avoidance systems etc.) are dual-use technologies.

The UCAV technology is still in its infancy and has not yet been demonstrated on the battlefield. The United States is perhaps the only country with enough resources to expend on this unproven (and thus far, unexperimented) technology. The high costs involved in experimenting with this immature technology means that small and medium powers should for the time being observe the trends in UCAV development in the US and not expend their limited resources pursuing it. It is important to remember that research and development costs continue to approximate double that of procurement costs.\(^88\) Singapore realizes that its limited resources do not permit it to work the entire range of UAVs as compared to those undertaken by the US.\(^89\) Singapore is working on a naval surveillance UAV named Lalee (low-altitude, long-enduring endurance). Presently in partnership with Singapore on the Lalee UAV, the European Aeronautic Defence and Space Company (EADS) has also shown a keen interest in other collaborative ventures with Singapore.\(^90\) The US, France and Sweden have shown an interest in Lalee and are interested in collaborating with Singapore on it.\(^91\)

Singapore’s success in technologically sophisticated endeavors like Bionix makes it well positioned to enter into defense-industrial ventures (like collaboration, license production etc.) with other countries like Israel to meet the requirements of its armed forces and also to develop the export potential of the local defense industry.\(^92\) Singapore’s Defence Minister, Tony Tan, has in the past stated that Singapore will strengthen links with existing partners.

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\(^{88}\) In 2003, the US spent $394 million on the procurement of the Global Hawk, the Predator, and the Shadow UAVs, but spent $805 million on UAV R&D costs. See Bone and Bolkcom, op. cit., p.6.


and forge new ones as its defense technology needs increase.\textsuperscript{93} Singapore is developing the Firefly UAV with Israeli technology. It is believed that Firefly is a high-altitude, high-speed reconnaissance platform, which can be converted into a cruise missile by fitting a warhead.\textsuperscript{94} Singapore has in the past sold the Israeli UAV Blue Horizon to the Philippines. Singapore Technologies manufactured this UAV under contract with the Emit Aviation Consultancy of Israel.\textsuperscript{95} Singapore Technologies is also working on several MAVs – Tailsitter, which is about the size of a golf bag, and the Sparrow, which is a palm-sized device. According to Tim Huxley, Singapore’s investment in UAVs will also help Singapore with low-intensity concerns like monitoring of population and shipping movements to the south.\textsuperscript{96}

In a nutshell, in spite of their size and budget constraints, UAVs are likely to find their way into the arsenals of small and medium powers. They will perform a central function in battlefield surveillance and even armed reconnaissance. MAVs with their potential to substantially transform urban operations and special operations missions will also interest small and medium powers. UAVs will also play a key homeland security role for these states. In addition to this, collaboration (especially in the area of research and development), licensed production and joint marketing are other areas that will allow small and medium powers (and maybe even some regional powers and the US) to come together for a joint effort.

6. CONCLUSION

The unmanned aerial vehicle is an innovative weapon system that avoids placing a pilot in harm’s way, but it is not a truly disruptive technology as there will always be missions that will require the manned aircraft. Likewise, the unmanned platform has lesser flexibility, greater vulnerability and cannot analyze its environment. It is clear that many advanced unmanned platforms are as expensive as manned aircraft and their high cost makes them attritable, not expendable. Their software complexity, automation and communications

\textsuperscript{93} “Defence technology to be Singapore’s cutting edge: defence minister”, Agence France Presse, 06 September 2000.


architecture makes them operationally unreliable for many missions. Thus far, communications technology has limited the effectiveness of the unmanned platform, especially its armed counterpart.

UAVs also face considerable challenge from competing systems like satellites and TLAMs. Satellites not only provide better situational awareness, but also avoid international norms for violating national/sovereign airspace and are thus far invulnerable to shoot down. TLAMs have proven superior in weapon delivery roles. However, many dull, dirty and dangerous missions will see an increased role for the unmanned platform.

UAVs are going to perform the critical ISR mission in future military operations where they are likely to perform tactical missions together with their manned counterpart upon obtaining cues from satellites. UCAVs and armed UAVs shall also perform strike and pre-emptive SEAD missions in the future, but are not likely to perform reactive SEAD missions due to the proliferation of sophisticated IADS worldwide. They are also likely to play an important but limited role in electronic attack missions. The proliferation of sophisticated counterair assets makes them unsuitable for counterair missions and communications and automotive technology limitations together with political ones (the authorization to fire) reduces their usefulness for combat missions. It is unlikely for the unmanned platform to make significant inroads into the force application role in the policy relevant future.97

Small and medium powers are likely to find UAVs useful in ISR roles only as the unmanned combat platform is still an unproven technology and is in its developmental stages. However, their potential for homeland security and commercial applications will give them prominence in the years ahead. The defense-industrial sector is likely to see an influx of new players from the commercial sector, as advances in the unmanned technologies are likely to have important commercial applications.

However, it is important to remember that unmanned platforms can never replace the manned aircraft, as the unmanned platform is just a machine that takes cues from the environment and follows a pre-defined set of instructions to react, i.e., it cannot analyze its environment. Even

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97 Advances in nanotechnology can boost the role of the unmanned platform (MAVs) in a combat mission. However, it must be remembered that advances in other new systems such as kinetic energy weapons and directed energy weapons will reduce the combat effectiveness of manned as well as unmanned aviation.
AI systems can at best only improve existing technology; they can never supplant the human under the uncertainties and rapid changes of war.
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