UAVs: CAPABILITIES AND TRENDS A CASE STUDY OF THE USA, EUROPE AND ISRAEL

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The recent wars in Afghanistan and Iraq have proved that acquisition and rapid dissemination of information is the key to successful warfighting. It is also a well established fact that these campaigns benefited immensely from the contributions of unmanned aerial vehicles (UAVs) in this field. The emergence of missile carrying UAVs like the Predator and autonomously flying Global Hawk in these wars has unleashed a revolution in warfighting.

The history of unmanned aircraft dates back to World War I, when unmanned aircraft were tested by the USA but not used in combat. World War II became the launch pad for the use of unmanned aircraft as target vehicles and air-to-ground weapons. The war in Vietnam exemplified the versatility of UAVs by exploiting the hitherto untapped potential of Ryan Firebee drones, also named Lightning Bug, which were utilised successfully in nearly 3,500 missions over China and heavily defended North Vietnam. These missions started with information collection using daylight cameras and gradually progressed to eventually include electronic intelligence (ELINT) missions to electronically map fire control radars of surface-to-air missile (SAM) systems[1]. The adaptability potential of these systems can be assessed by the fact that Firebees which were initially flown in 1970s were recently modified and successfully flight tested for weapon delivery role on December 20, 2002[2]. However, even with these exploits,

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1. Laurence R. "Nuke" Newcome, *Unmanned Aviation: A Brief History of Unmanned Aerial Vehicles* (Virginia:AIAA,2004), ch. 11.
2. In a news report by Jefferson Morris titled "Northrop Grumman Modifies BQM-34 Firebee to Drop Payloads," *Aerospace Daily*, January 22, 2003.

the growth of UAVs has been protracted. The developments have been slow, with militaries the world over being reluctant to incorporate unmanned aircraft into the regular force structure mainly due to immature technologies and lack of funding for research compared to other aerospace platforms like satellites and manned platforms.

The US National Defence Authorisation Act for Fiscal Year 2001, stated, "Within ten years, one-third of US military operational deep strike aircraft will be unmanned."

The present growth phase of unmanned aviation started with successful exploitation of UAVs by Israel in Bekaa Valley in 1982[3]. This regenerated interest in the combat potential of UAVs, and the advent of micro-electronics led the USA to invest in the technologies for further upgradation of these systems, eventually resulting in the present day successes of the Predator and Global Hawk UAVs. Technological advances and confluence of established potential and recognised needs has brought about a marked change in the perceived military value of UAVs. The unmanned attribute of UAVs is increasingly becoming important in present age capabilities-based planning for effect-based operations. A large number of developed and developing countries have demonstrated an increased acceptance and acquisition of unmanned systems. Evolving military doctrines are incorporating UAVs as integral assets of warfighting.

US interest in UAV systems was clearly spelt out in the US National Defence Authorisation Act for Fiscal Year 2001, which stated, "Within ten years, one-third of US military operational deep strike aircraft will be unmanned." While most of the development in UAVs around the world is military oriented, Japan has the largest fleet of civil UAVs in the world, more than 2,000, engaged mainly in agriculture related activities.

Historically, the development of UAVs has been largely crisis dependent. All the major military and political conflicts since World War I have fuelled interest in unmanned aviation. The Predator B and RQ-4B (upgraded Global Hawk) are

3. Jasjit Singh, *Air Power in Modern Warfare* (New Delhi: Lancer International, 1985).

war-time upgrades of initial models which, in spite of massive cost overruns, have been possible due to war-time urgency.

Field experience backed up by research in unmanned technologies is aggressively expanding the operational envelope of UAV systems. The present status of UAV technology and the untapped potential is aptly summed up in the statement, "Arming of the Predator with hellfire is akin to mounting a gun on a biplane." UAV systems include small and micro systems, medium to large systems, fixed and rotary wing and near space systems[4]. Mission capabilities vary widely depending on the intended role which dictates the type of sensors/payload, range and endurance, altitude of operation, manoeuvrability, speed and stealth characteristics.

The USA is the major operator of military UAVs in the world, followed by Israel and a host of other countries. Thirty-eight countries are developing or have shown interest in development of UAVs while more than 65 countries are operating UAVs for various roles, including aerial targets[5]. Most of the research in unmanned technologies is centred in the USA, Israel and Europe. This paper is an effort to summarise the major existing capabilities of the USA, Israel and Europe along with ongoing developments and emerging trends in UAV technologies. A description about UAV systems/sub-systems is followed by UAV capabilities and developments in the USA, Europe and Israel. Developments in UAV technologies in these areas are also covered along with the emerging trends.

UAV SYSTEMS

Earlier, UAVs were radio controlled model aircraft which had basic command and control functions, with an optical camera mounted on the body for aerial imagery on the wet film. Present generation multi-role autonomous UAVs are very advanced systems capable of all weather day and night operations. These UAVs vary from bird size to that of cargo aircraft, and require extensive support for operational exploitation. Autonomous air vehicle operations are becoming the norm on large UAVs. Autonomous vehicles are capable of conducting

4. Near space systems operate at altitudes above controlled air space and below low-earth obit. USAF Strategic Vision 2005 considers this range to be between 65,000 ft and 3,25,000 ft.
5. *Jane's Unmanned Aerial Vehicles and Targets* (Surrey UK: Jane's Information Group).

unassisted missions, including launch and recovery with optional controllability. These vehicles, when operating beyond line of sight (LOS), are controlled and monitored through satellite links. Directly controlled vehicles operate within radio horizon and have their command and control for launch, recovery, mission control and data exploitation located together. The complete UAV system comprises an air vehicle with payload, ground control and ground support. The aerial vehicle primarily acts as a platform for deployment of sensors and other payload over the desired area. Ground control effectively controls the aerial vehicle in an effort to ensure safe launch, recovery and effective exploitation of sensors and other payload. Ground support consists of technical and ancillary support for effective deployment, operation and exploitation of the system, including data fusion and dissemination facility.

Air Vehicle

The technologies developed for manned aircraft and other systems have been modified for use on UAVs. Most of the airframe features are proven designs on manned aircraft. Design features suited to UAVs for low radar visibility have started appearing now, like engine intake on top of the fuselage in experimental X-45 and X-47 UCAV (armed UAV) designs of the USA and similar features in the CORAX of the UK and Neuron of the European consortium[6]. The initial UAV engines were the ones being used on motorcycles and snow scooters[7]. Internal combustion engines are a preferred choice for short to medium range UAVs due to lower fuel consumption resulting in longer endurance albeit with slow speeds and lower climb rates. This provides longer loiter times with small fuel loads. The long range higher payload UAV, the Global Hawk, has a turbofan engine for higher propulsive power. Other proven designs of long endurance like the Predator and Heron are also being upgraded with turbo prop and turbofan engines for enhanced performance. UCAVs, planned to penetrate the adversary's air defence (AD) systems to reach targets deep inside, will have turbofan or jet engines to give higher speeds for reduced exposure time, thus,

6. *UAS Roadmap 2005*, US Department of Defence, Washington DC, August 4, 2005 and <http://www.dassault-aviation.com/gb/actualite/actualite/article>.
7. The Predator A uses a modified internal combustion snow scooter engine.

increasing survivability. Navigation is generally based on the inertial navigation system (INS) with embedded satellite navigation like the global positioning system (GPS) for high accuracy and operations in the GPS jamming environment. Differential GPS is now being used for automatic launch and recovery systems.

Imaging Payloads

Electro-optical (EO) systems along with thermal imaging infrared (IR) systems have become standard fitment on UAVs for both day and night operations. IR works in the non-visible light spectrum and, thus, is able to identify conditions which are not discernible to the naked eye, like disturbances in the ground surface or concealed heat sources. IR systems are limited by degradation in quality of image due to thermal crossover[8]. Image intensifiers coupled to the charge coupled device (CCD) are also used for low light observations. However, the performance of image intensifiers gets badly affected by bright fires, smoke and totally dark conditions. Laser designators and range finders are integrated with optical systems for target designation. These optical systems are housed in gyro stabilised mountings. The multi-spectral targeting system (MTS) deployed on the Predator is used for target detection, ranging and tracking, and consists of a television camera, thermal imager, laser illuminator, eye safe laser range finder with spot tracker and an image fusion system for armed Predators. The dual band LOROP (long range oblique photography) system is being planned for standoff surveillance capabilities. Major producers of these advanced systems are the US, Europe, Israel and South Africa.

EO/IR systems are supplemented with synthetic aperture radar (SAR) for all weather day and night imaging. Initially, the size and weight of SAR was the major constraint for its deployment on UAVs[9]. SAR is an active radar which uses microwave pulses for scanning to produce detailed imagery in day and night with ability to penetrate atmospheric obscurities like clouds, rain,

8. Thermal crossover – when sky and land temperature is practically the same. This leads to grey-out in IR imagery.
9. SAR technology was developed for scientific and environmental research for satellite-based exploration and monitoring but has been modified for military surveillance on manned and unmanned platforms.

snow and fog. Multiple sensor systems have been developed for UAVs which carry EO/IR and SAR with MTI (moving target indicators) like the ISS (integrated sensor suite) system carried on the Global Hawk which is capable of tracking multiple moving targets either on the ground or air with a 100 km standoff capability. Europe and Israel have also developed their versions of SAR. Britain is projecting its I-Master SAR/GMTI (ground moving target indicators) for use on its Watchkeeper UAV programme. The French EADS has developed one of the lightest SAR MiSAR (Miniaturised SAR). MiSAR is a high resolution K-band radar weighing only 4 kg for use on small tactical UAVs which could not use SAR earlier due to payload capacity constraints. SAR technology is still under development, and research is promising for increasing penetration capabilities.

Non-Imaging Payloads

UAV roles are growing beyond intelligence, surveillance, reconnaissance (ISR) with the increased availability of physically (size and weight) and financially viable non-imaging payloads. Military missions like suppression of enemy air defences (SEAD), electronic warfare (EW) and chemical and biological warfare are opening up with the enhancement of UAV capabilities. The development of these systems is mainly centred in major UAV producers i.e. the USA, Europe, Israel and South Africa. All these roles which were hitherto in the domain of manned aircraft have the payloads developed for the same, which are now being reengineered to produce smaller systems for use on UAVs. UAVs like the Predator have been equipped with Hellfire air-to-ground missiles, JDAM[10] (joint direct attack munitions), SDB[11] (small diameter bomb) and Stingers. Israel's Harpy is a dedicated UAV for SEAD. The German Taifun UAV is also built on similar lines but targeted against tanks and armour.

EW payloads for UAVs had been limited due to large power requirements for active systems. Passive systems targeted at electronic mapping of specific systems

10. JDAM —are tail kits devised to steer the conventional bombs under GPS guided inertial navigation.
11. SDB a mmall diameter bomb being developed by the USAF. It is a 250 lb bomb measuring six inches in diameter and six feet length, with 50 lb explosive. This low cost, high lethality precision strike weapon for multiple platform deployment is planned to give up to 60-mile standoff range.

or communications have been in use since the Vietnam War. With the concept of UAVs operating in groups gaining ground, limited range smaller EW payloads requiring less electrical power are being developed and employed. The US Joint UCAS (JUCAS)[12] was being developed with diverse mission capabilities, including electronic attack based on the active electronically scanned array (AESA) radar and electronic surveillance measures (ESM) equipment. The Global Hawk is the first UAV to carry a miniature ESM/ELINT/radar warning receiver providing parametric signal measurement, signal homing facility and formatted data reports. Standalone signal intelligence (SIGINT) capabilities for UAVs have been tested on the Predator and a lightweight communication jammer employed on the Dragon Drone mini UAV of the US Marine Corps (USMC). The German KZO UAV has been flying with a lightweight low power ESM and direction finder system. The Euro Hawk, a derivative of the Global Hawk, is being developed by Germany with HALE ELINT Payload (HEP) radar sensor to identify all types of EM sources and combining it with the commercial intelligence (COMINT) system for full SIGINT capability. The Israeli EL/L-8385 system and South African ESP (electronic surveillance payload) are reported to be capable of generating real-time electronic ORBAT (order of battle) reports with an ability to operate in congested urban communication environments.

UAV CATEGORIES

UAVs have been traditionally categorised as strategic or tactical, based on the operational range. Short to medium range UAVs involved in tactical ISR with EO/IR sensors comprise the bulk of UAV systems globally. These UAV systems generally operate within 25 to 80 nautical miles (nm) radius relying on LOS data link for control and data transmission. The range is normally extendable by using the data link relay. Small fuel efficient internal combustion engines are used which give an endurance of six to ten hours at cruise speeds of 60 to 85 knots (kts). Though operational ceilings go up to 10,000 ft, most of the operations are limited to below 4,000 ft to 5,000 ft due to sensor performance which is generally limited to detection

12. JUCAS of the US was conceived for unified efforts in the US for development of UCAVs for the armed forces. JUCAS has now been shelved by the US in favour of separate developmental efforts to meet differing requirements of the USAF and US Navy.

of tank size targets at 8 to 10 km, recognition at 5 to 8 km and identification at 4 to 5 km range[13]. The maximum proliferation of UAVs has been in this segment due to lower costs and successful exploitation as force multipliers. Strategic UAVs are long range capability systems operating autonomously with satellite data links to control stations. At present, medium and long range UAVs in the world are limited to the USA and Israel. The erstwhile USSR had high speed, long range UAV designs in production using modified turbojet engines of the MiG series of fighters. These were good for high speed single pass reconnaissance but lacked loitering capability due to low endurance. The development of the long range, long endurance category of UAVs is very resource, time and cost intensive with associated risk similar to the development of new manned aircraft. Financial constraints and technological implications in these types of projects have forced many countries to take the collaborative approach to development. Short range tactical UAVs have been an attractive option for various countries due to reduced financial and technological implications which are the major reasons for the proliferation of low cost UAVs beyond the boundaries of nation states to individual organisations[14].

UAVs capable of locating, tracking, designating and attacking targets with lethal and non lethal weapons epitomise the unmanned aviation technology.

UAVs capable of locating, tracking, designating and attacking targets with lethal and non-lethal weapons epitomise the unmanned aviation technology. These systems are equipped with EO/IR sensors, laser designator and optional weapon launch capability or electronic warfare (EW) equipment. This capability, which provides real-time situational awareness with optional kill capability, helps a tactical battle commander to fight the enemy and not just the plan.

UAV CAPABILITIES OF THE USA

The USA has been in the forefront of both manned and unmanned aviation. Military interest had fuelled the growth of both manned and unmanned

13. Inference drawn from data given in *Jane's Unmanned Aerial Vehicles and Targets* (Surrey UK : Jane's Information Group).
14. Reported violations of Israeli air space by UAVs of Iranian make operated by the Hezbollah militia is a recent example of such type of proliferation.

aviation, of the latter in fits and starts. The growth of unmanned aviation has been affected by many factors, mainly expectations outstripping technological capabilities, and policy decisions favouring satellites and manned assets over unmanned aviation. However, the research and development (R&D) efforts were always going on in the background, though much slower and more poorly funded than comparative efforts in other aerospace initiatives. In fact, the successful Predator and Global Hawk are also built on the concepts validated by the Defence Advanced Research Projects Agency (DARPA) in simmering R&D efforts in unmanned aviation technologies[15]. In the last more than a decade, UAV development in the USA has followed two distinct patterns. Requirement of long endurance missions for persistent ISR resulted in large UAVs like the Global Hawk weighing over 25,000 lb. Demands of asymmetric warfare in urban landscapes forced the smaller UAVs to shrink further to micro size for niche roles. Operation Iraqi Freedom has become the testing ground for a large number of military UAV systems being developed by US research labs. In the recent past, the Predator has been the most successful UAV of the USA in the medium range and the Global Hawk in the long range. At an average price of US $10 million and US $ 60 million, the Predator and Global Hawk UAVs are not cheap but due to the results of recent combat deployment, the demand for these UAV systems is growing. A lot of small and mini UAV systems like the Shadow 200, Dragon Eye, Hunter, Pointer and FPASS also are being successfully used by the US military. The capabilities of some of these successful UAV systems are discussed here to get an insight into current US potential in this field of aviation.

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15. Technologies and concepts for the Predator and Global Hawk have been harnessed from earlier successful technology demonstrator projects for endurance UAVs by DARPA in the 1980s and 1990s. The Predator is a growth version of the Gnat UAV which was developed from the Amber system produced under the DARPA project. The Global Hawk traces its roots to the Condor project for endurance UAVs undertaken by DARPA in the late 1980s.

Global Hawk

The Global Hawk is a high altitude, long range endurance UAV capable of loitering for more than 24 hours at 1,200 nm range while flying at 65,000 ft altitude for surveillance in all weather conditions[16]. The high altitude and long operational radius increases the survivability and operational flexibility of this large platform which carries additional self-protection in the form of a radar warning receiver, self-defence jammer and towed decoy. Approximately 3,000 lb payload on the Global Hawk consists of an ISS which is a sophisticated set of active and passive imaging sensors with a common image processor. Passive sensors consist of the EO/IR system and active sensors comprise SAR with GMTI. The EO and IR optical sensors share common optics, thus, cannot be used simultaneously but it takes the operator just five seconds to switch from EO to IR or IR to EO[17]. Hughes Integrated SAR (HISAR) is capable of multiple modes, giving one metre resolution in a wide area search and 0.3 metre in spot mode at 200 km slant range. The GMTI mode can detect and track moving targets with speeds as low as four knots. For enhanced standoff capability, the range performance of ISS has been further increased by 50 per cent in EISS (enhanced ISS). Hyper wide SIGINT sensors are already employed on the Global Hawk which will be improved to high and low band gradually. ELINT payloads have been tested on the Global Hawk and hyper-spectral imaging (HSI) sensors are also being developed for effective camouflage penetration.

The Global Hawk has been built with a high level of autonomy to minimise the human interference in mission management. The onboard mission management computer controls the vehicle as per the mission plan which includes possible contingencies also. Pre-programmed decision trees are built to address every possible failure during each part of the mission. Due to the detailed mission planning requirement, and mission plan preparation time stretching to almost 24 hours[18], the sortie generation rate of the Global Hawk has

16. This data is for the RQ 4B, the upgraded production version of the Global Hawk.
17. John G. drew, Russell Shaver, Kristin F. Lynch, Mahyar A. Amouzegar, Don Snyder, *Unmanned Aerial Vehicles End to End Support Considerations* (Santa Monica: RAND Corporation, 2005).
18. As per an estimate, it used to take almost 8,000 mouse clicks to plan one mission. Since 2003, with the help of the advance planning software tool automatic contingency generation (ACG), mission planning time has reduced to 12 hours from earlier 24 hours.

been comparatively low. However, this long drawn complex mission plan is responsible for successful autonomous operations over a long range for long durations, enabling the Global Hawk to revolutionise the battle space. High level of autonomy in the Global Hawk enabled it to handle an inflight engine failure over Afghanistan, resulting in a successful engine off emergency landing[19]. Long range permits the operations from far off secure places. Launch and recovery is controlled from these forward bases, whereas mission control is exercised from Beale Air Force Base, California, in continental USA, exclusively, through wide band satellite link. This capability is being projected for fast reaction global reach with a maximum of three dispersed launch bases outside the USA[20]. Mission control based in continental USA plans and monitors the execution of the mission, including payload exploitation. Though the system is fully autonomous, the operations are monitored throughout the mission with an optional intervention in case of requirement for retasking or emergency. This concept of operations involving trans-continental flights of the Global Hawk has given rise to requirements of regulations for controlling and regulating flights of UAVs through civil air space.

The impact of this highly capable ISR platform was visible during Operation Iraqi Freedom where a total of 15 missions flown by Global Hawks, amounting to approximately 3 per cent of total ISR missions by Coalition forces, resulted in 55 per cent of time critical data on air defence targets. Targets unmasked by Global Hawks included 13 SAM batteries comprising 50 launchers, 300 canisters, 70 missile transporters and 300 tanks[21]. These 300 Iraqi tanks were detected while regrouping during a three-day, severe sandstorm which halted the US Army in its tracks. The US Air Force (USAF) has plans to increase the capabilities further with phased introduction of advanced SIGINT and AESA radar under the Multi-Platform Radar Technology Insertion Programme (MP-RTIP). AESA is a scalable multi-functional radar with the ability to search, detect, track, communicate and jam simultaneously. The Global Hawk is a very attractive potential weapon

19. The Global Hawk has suffered engine failure twice over Afghanistan. In the first instance, the UAV crashed while gliding to reach a border airfield in Pakistan. This was reported by Associated Press on July 12, 2002.
20. n. 17, pp. 64, 66.
21. Refer "HALE Program Overview" at http://www.northropgrumman.com/unmanned/globalhawk/overview.html.

platform with the ability to carry 1,000 lb on hard points under each wing. This option has not been officially taken up by the USAF citing the politically sensitive nature of the weaponised platform traversing through the air space of neutral nations on long haul missions[22], though this explanation does not hold much ground now as the Predator B, a weaponised platform, is already making inroads in Global Hawk operational territory. It is evident from Table 1 that the Predator B compares favourably against the Global Hawk. However, with the open option of higher payload on strengthened wings, the Global Hawk can be transformed into a formidable platform, with capability to carry a variety of weapon loads, including nuclear weapons and long range anti-ship missiles.

A Global Hawk with present generation sensor suite is likely to cost over US $ 54 million which does not include the cost of a ground station at US $ 16 million.

Though the immense potential of the Global Hawk is being aggressively explored by adding new capabilities, its cost is also moving up. A Global Hawk

Table 1.

	PREDATOR A	PREDATOR B	Global Hawk RQ 4B
Commn	C Band and VHF LOS, Ku Band Satcom BLOS with 1.5 mbps data transfer rate		X Band and VHF LOS Ku Band Satcom
Speed max/ loiter	135/70 kts	225 kts	340/310 kts
Endurance	40 h	32 h / Mariner with 49 h	36 h
Payload	450 lb	3,000 lb	3,000 lb
Ceiling	25,000 ft	50,000 ft	60,000+ ft

22. USAF official stand while countering the testimony of Gen Franks of the US Army in the US Senate for a weaponised Global Hawk, on July 9, 2003. Reported in *Aerospace Daily and Defense Report* by Marc Selinger.

Weapons	2 Hellfire missiles	10 Hellfire ,Other options-Maverick/ sidewinder/ AMRAAM/500 lb GBU 12/ Stinger/ JDAM/ SDB	Not yet weaponised
Sensors	TESAR, MTS with IR/EO and laser designator and tracker	LYNX SAR , MTS-B with IR/ EO and laser designator and tracker	EO/IR , SAR - GMTI , Hyper wide-SIGINT, Future upgradation-AESA and SIGINT-high / low band, Hyper-spectral sensors
Cost	$ 4.8 million	$ 9.938 million* (GAO estimate- $ 19.2 million)#	$ 56.2 million* (GAO estimate- $ 130.5 million) #

* Unit flyaway cost indicated by manufacturer. # Total operational cost.

Source: *Unmanned Aerial Vehicles End to End Support Considerations* (Santa Monica: RAND Corporation, 2005), http://www.northropgrumman.com/unmanned/index.html , *Assessment of Selected Major Weapons* (US GAO Report GAO-06-301, March 2005), *Global Hawk Unit Cost Increases* (GAO-06-222R, December 15, 2005).

with present generation sensor suite is likely to cost over US $ 54 million which does not include the cost of a ground station at US $ 16 million. The cost will go up further with plans to upgrade the sensor capabilities similar to the U-2 aircraft. In spite of the increasing cost, the Global Hawk will still have an advantage due to prolonged loiter capability, much beyond any manned aircraft. Notwithstanding the immense advantages of this system, it is a fact that till date it has been used in an environment bereft of any credible threat to its operations. Due to its large size, it is a very attractive and easy target for high altitude SAM or fighter launched air-to-air missiles and will require additional protection akin to tied escorts in the vulnerable phases of the mission. Also, it will necessitate stealth design and features, pushing it further up in the cost spiral. The only option in the present configuration is to use it in a standoff mode, out of the evenly matched adversary's effective reach. A separate platform for penetrating ISR, on the lines of the cancelled Dark Star UAV, is required to complement the Global Hawk's standoff surveillance.

Predator UAV

The Predator UAV shot to fame after carrying out a successful strike against a moving target in Yemen in 2002 by controllers sitting in Djibouti[23]. The command and control through satellite communication link is an inherent design feature of the Predator system. The weapon carrying and launch capabilities were subsequently added as part of expansion of the operational envelope. It was developed as a medium altitude long endurance UAV, powered by a modified snowmobile pusher propeller engine[24], for an ISR role with EO/IR and SAR sensors, with all weather imaging capability. The system graduated to multi-role capability with the addition of payloads in the form of SIGINT payload, laser designator and tracker in conjunction with optical sensors, chemical detection sensors and Hellfire missiles for ground attack. The Lynx SAR deployed on the Predator B is capable of 4-inch resolution at 15-mile range in spot mode[25]. The system is capable of detecting, locating, designating, acquiring and attacking the target with the multi-spectral targeting system (MTS-B) which consists of an IR/EO imaging system along with a laser designator and tracker. Common optics with fast switching option is used for EO and IR systems. The Predator is capable of autonomous flight, navigation and also approach and landing on a predesignated runway with an integrated automatic recovery system using differential GPS. Automation of flight management, including launch and recovery, has been included with an aim to minimise manual inputs which have been identified as the major cause of mishaps in UAVs. This also facilitates the concept of multiple UAV control by a single operator. The Ku band satellite link is used for beyond line of sight command and control of various flight control and sensors. The USAF Predators flying out of Balad Air Base in Iraq are routinely controlled by

23. From an interview of Gen John Jumper. USAF Chief of Staff, reported in CBS news on January 8, 2003.
24. n. 17, p. 75, Table B.1.
25. *Defence Update*, Issue 2/2005.

operators sitting across the globe in the US mainland[26]. This gives flexibility in operational deployment while reducing logistical demands.

The Predator's impact on surveillance was evident early in its operational role when reliable real-time intelligence by Predators, while monitoring the movement of heavy weaponry in Bosnia, led to the North Atlantic Treaty Organisation (NATO) forces resuming bombing, forcing the parties to sign the Ohio Peace Accord in December 1995[27]. The initial ISR only system, the RQ-1 (Predator A), was designed as an optionally expendable vehicle by restricting the cost[28]. The system upgradation necessitated by operational experience has increased the cost substantially, resulting in severe restrictions on expendability. The emergence of the Predator B is a classic example of growth guided by operational experience. Lessons learnt from the Balkans deployment projected the requirement of improvement in survivability against ground fire, possibility of weather avoidance and weaponisation for time sensitive targets. The system was upgraded by adding hard points for weapons on strengthened and bigger wings, anti-icing[29], increased speed and operational altitude for enhanced protection against ground fire (small arms and anti-aircraft guns). Hellfire missiles were mounted on the Predator to strike time critical targets. The Predator B is a heavily armed UAV capable of carrying ten Hellfire missiles compared to two Hellfire missiles on the Predator A[30].

The Predator has logged more than 150,000 hours, mostly in combat, since its first flight in 1994[31]. This was the first UAV to have operational control through satellite data link. Its evolutionary architecture has allowed integration of specific payloads, giving some flexibility of configuration to the user. The Predator B can be equipped either with MTS-B or Lynx SAR for the mission. The

26. Mission control of USAF Predators in Iraq is exercised from Indiana Springs, AF Base Nevada. Refer http://www.afnews.af.mil/iraq/balad/032406-predators-balad.htm>.
27. Refer <http://www.edwards.af.mil/articles98/docs_html/splash/may98/cover/bosnia.htm>.
28. As per USAF requirements, the cost of equipment has to be less than US $ 5 million to qualify as an expendable item. The procurement cost of the Predator A was capped at maximum US $ 5 million for it to be expendable. Refer n. 17, pp. 88, 89.
29. The anti-icing technology used on the Predator combines a glycol-based "weeping wing" leading edge system with an ice detector and a heated air data system.
30. Ibid., p. 87.
31. Press release by General Atomics on September 20,2005, available at < http://www.ga.com/news.php?subaction= showfull&id= 1127224535&archive=&start_from=&ucat=1&>.

operator has the flexibility to decide the external payload and endurance depending on the mission requirements and the possibility of encountering icing conditions. The endurance of the vehicle reduces when used with the anti-icing system and also with external stores. The wing with anti-icing features is not standard and is interchangeable with a clean wing[32]. The maritime version of the Predator named Mariner is being built for 49 hours endurance.

A comparison of the operational features of Predator models listed in Table 1 makes it clear that enhanced payload performance of the Predator B comes at double the cost of the Predator A. At US $ 10 million, the Predator B is a very capable system, but much beyond the expendability limits.

Tactical UAVs

These UAVs form the bulk of the US inventory. As of February 2006, the US armed forces had 3,048 UAVs of various types on their inventory. Over 88 per cent of these unmanned aircraft were small UAVs[33]. Major UAVs in this category are the Shadow 200, FPASS, Pointer and Raven operated by the US military. These systems fly at about 500 ft with speed varying from 30 to 70 kts, giving endurance in the range of one to two hours. These are portable UAVs with EO/IR sensors for day and night operations, controlled through specially configured laptops. The payload generally comprises the switchable EO or IR sensor due to weight considerations. These UAVs, with autonomous flight characteristics, are capable of launch and recovery without a runway. Low cost, coupled with ease of use, and exploitation of data, has made these UAVs the most in demand equipment of US ground troops. Field experience has shown that deployment of short range small UAVs has given a major boost to battlefield situational awareness. At an average vehicle cost of US $ 50,000 to 70,000, these UAVs have proved to be a very effective situational awareness tool.

UCAVs

The weapon launch capability of the Predator has made it an armed UAV

32. n. 17, pp. 82, 83.
33. *Unmanned Aircraft Systems : Improved Planning and Acquisition Strategies Can Help Address Operational Challenges* (GAO-06-610T, Washington DC, April 6,2006).

(UCAV). However, UCAVs are conceived to be large, fast and stealthy UAVs capable of suppressing enemy air defences and executing strike missions in support of manned operations. US efforts were focussed on the JUCAS project spearheaded by DARPA for the USAF and US Navy. In February 2006, this project was suspended after a lot of work had been done. The project appears to have become a victim of differing requirements of partners that arose during the long gestation period from conception to operation. The success of the weaponised Predator with expanded envelope has also played a role in the change of thinking. The USAF is veering towards a long range unmanned bomber and the US Navy is likely to go for ship-based UCAV capability. The technologies developed and demonstrated for JUCAS include the network-based operating system which enables interoperability among various platforms, sensors and sub-systems. It enhances the situational awareness of the system to a level which enables it to take independent decisions for the mission accomplishment. In April 2004, after obtaining target coordinates and weapon release authorisation, an X-45 A[34] demonstrated successful autonomous release of a GPS guided weapon from 35,000 ft while flying at 0.8 Mach[35].

The temporary change in the US track towards UCAVs may result in some delay but ultimately, UCAVs will rule the skies or share the battle space with the manned counterparts. Whatever be the US plans for UCAV progress, these emerging technologies will have a profound impact on the UAV's operations in future.

UAV CAPABILITIES OF EUROPE

Europe lags far behind the US in the field of UAVs and the largest gap lies within the high altitude long endurance (HALE) UAV and UCAV segments. Europe is engaged in a couple of high altitude and medium altitude projects but not at the same level of intensity as the USA. In spite of the proliferation of tactical UAVs in Europe, the development of long-endurance UAVs has been much slower.

34. The X-45 A had been developed as a scaled prototype by Boeing for JUCAS.
35. Dr Mike Francis, "Joint Unmanned Combat Air Systems : The Have Blue of the 21st Century" (a presentation on JUCAS overview at DARPATECH 2005, Anaheim, California, August 09 -11, 2005).

After an initial lead in radio controlled target drones by the UK, Europe did not show any aggressive inclination towards UAVs. Development of manned fighter platforms progressed with notable successes like the Mirage series, Tornado, Hawk, Gripen, Jaguar and Harrier. Short range tactical UAVs for use by land forces have been developed and deployed by various countries in Europe. The increasing cost of new technologies required for medium to long range UAVs has forced the European nations to forge alliances and go for joint development and production. The formation of the European Union has given a push towards unified efforts in R&D in Europe. Efforts and funding are being pooled by various countries in a few medium to long range UAV projects under development with US or Israeli collaboration. Major players in Europe pushing for UAVs are France, Germany, Britain, Sweden and Italy. Existing European UAVs fall within the short range tactical category with LOS links limiting ranges to within 100 km and lightweight payloads. Most successful have been the Phoenix, Crecerelle or Sperwer, CL-289 and LUNA. These systems have been employed in combat conditions during NATO operations in Bosnia and Kosovo, and Allied operations in Afghanistan in support of land forces.

France operates tactical UAVs like the Crecerelle, Fox AT and CL-289 with EO and IR payloads. It has developed capabilities to deploy the UAVs with either optical sensors or EW-U/VHF jammer or nuclear, biological, chemical (NBC) detection sensor payloads. The Crecerelle is based on the British platform Spectre and is being operated by various countries. France is also making efforts towards a medium and long range UAV christened Eagle UAV, based on the Israeli Heron platform, while Germany has been planning the Euro Hawk, an ISR and EW version of the Global Hawk. The six nations' collaborative effort, NEURON UCAV, is also led by France, which is likely to fly in the next decade.

Germany's tactical UAV LUNA is also within the 80 km range and these make up the numbers with the KZO UAV in the German forces for a tactical surveillance role. Germany is also progressing on deployment of a lethal non-recoverable TAIFUN UCAV which operates like Israel's Harpy but is targeted against tanks. With four hours endurance and a speed of 250 kmph, it is an autonomous fire and forget system which identifies the target in a 200 km range and than destroys it with a 20 kg shaped high explosive (HE) warhead. It is equipped with lightweight IR sensor and SAR package. The anti-icing system has been incorporated in the design for flying operations in icing conditions. It is being improved into the TARES (tactical advanced reconnaissance and strike) system which will give flexibility of optional control for the operator to identify the target and authorise attack.[36]

Britain has been operating tactical UAVs for a reconnaissance role. Its Phoenix and Spectre systems are short range systems with limited EO/IR payloads. After considerable experience in UAV operations, the UK has consolidated its ISR UAV requirements in the Watchkeeper programme which is likely to be based on Israel's Hermes family of UAVs. Technologies are being developed in various programmes like CORAX and Nightjar for future UCAVs. Italy also has been quite active on the UAV front in Europe. It is operating the indigenous Mirach UAV in the tactical role and the US Predator UAV in medium range missions.

The general capabilities of major European UAVs indicate that efforts had been mainly concentrated on tactical roles based on available technologies. This has been due to the lack of push towards UAVs, as a result of the spiralling costs of R&D, high risks involved, non-focussed approach and dependency on matured and less risky manned platforms. The impact of UAVs on recent wars has forced a rethink in Europe and future acquisition strategies are being redrawn with emphasis on UAVs. The European nations are displaying increased interest and resource allocation towards developments in unmanned aviation. At a global level, after the USA, Australia has already expressed an inclination to shift from JSF to a mix of JSF and UCAV with reduction in the projected requirement of JSF from 100 to 70. This worldwide appreciation of UAV potential is forcing a review of future force mix which is bound to get reflected in the acquisition strategies of the European nations also. A collation of operational capabilities of major European UAVs given in Table 2 highlights the limited payload and

36. http://www.army-technology.com/projects/taifun.

endurance of these systems.

Table 2.

	SPECTRE/ CRECERELLE/ SPERWER	FOX AT	PHEONIX	MIRACH 26	LUNA
Speed	86 kts	97 kts	85 kts	119 kts	85 kts
max/loiter	70 kts	39 kts	70 kts	78 kts	30 kts
Endurance	5 h	3 h	4.5 h	8 h	4 h
Payload	35 kg	15 kg	50 kg	35 kg	4 kg
Ceiling	13,000 ft	11,000ft	8,000 ft	11,000 ft	10,000 ft
Sensors	EO/IR or EW- Jammer Or NBC Detector		Day & Night IR sensor	EO/IR or Commn Relay or Passive ESM	Colour video camera or IR
MiSAR will be added as optional payload.					
Radius	70 to 100 km limited by range of data and control link				

Source: *Jane's Unmanned Aerial Vehicles and Targets.*

UAV CAPABILITIES OF ISRAEL

Resurgence in UAV development is attributed to the successful and innovative exploitation of UAVs by Israel in Bekaa Valley against Syrian SAM deployments. The Israeli development traces its root to the stagnating US efforts in UAV research. In early 1971, Israel procured twelve Ryan Firebee model 1241 UAVs from the USA for use against SAM systems operated by Egypt and Syria. These were used against Egypt in 1973. The Israeli aerospace industry worked on these systems and came up with credible reconnaissance systems, the Scout and Mastiff, which were used very effectively to neutralise Syrian air defences at the beginning of the Lebanon War in 1982. Thereafter, the dominance of the world UAV market by Israel is history. With more than 130,000 hours of UAV flight time, and exports to over 20 countries, Israel is one of the largest exporters of UAVs in the world, covering over 60 per cent of the world market outside the

USA and Japan. These successes are the result of a focussed approach towards requirement-based development.

Israel has a presence in both short to medium range and long endurance segments of UAVs. The tactical ISR segment is mainly covered by Searcher and Hermes UAVs. In the long endurance segment, the Heron UAV holds the world record for the longest demonstrated endurance flight of 52 hours[37]. The Heron's attractive payload and endurance capabilities are being further developed for a weapon wielding UCAV version, the Eitan. The Heron is developing as the sole challenger of the successful US models Predator and Global Hawk. The capabilities of this system are not widely publicised as this UAV system is yet to see any combat deployment outside Israel. However, the export restrictions and higher cost of US technologies have given an edge to Israel for forging joint or collaborative development arrangements with various countries across the world, based on existing Israeli UAV systems, apart from outright exports.

Heron

This long endurance system from Israel is the sole competitor in the world to the US Predator system. In fact, the Hunter II system of the USA is based on the Heron design. The Heron has demonstrated the longest flight of 52 hours while flying at 35,000 ft altitude. It can fly a pre-programmed mission autonomously from launch to recovery, including navigation and sensors operation while retaining the option of full or partial manual control. It can be pre-programmed for return to launch base in the event of control link failure. The Heron carries a multi-mission optronic stabilised payload (MOSP) EO/IR multiple option package like a TV with laser designator/ range finder or TV with FLIR or FLIR with laser designator/range finder. The radar system carried on the Heron includes SAR with MTI giving detection range up to 100 km in strip mode, with resolution varying from three to one metres. The radar has an onboard processor to convert the radar image to photogenic view. The narrow view spot mode is capable of 10 to 60 cm resolution, depending on the range which is used

37. IAI MALAT in a presentation by Dr Drora Goshen Meskin on July 11, 2005, available at < http://www.csl.ulg. ac.be/ haas /WS1/11%20July%202005/Session%201/Presentation%204_Goshen.pdf.

for target classification. The maritime radar is capable of air-to-air search also, with the capability of tracking 32 targets simultaneously.

France has selected the Eagle, a version of the Heron, for its strategic ISR requirements and further development. This version is powered by internal combustion engines. A more powerful and potent version of the Heron with capabilities of weaponisation is being developed with a turbo prop engine. Sketchy reports indicate it to be a 4,000 kg all up weight (AUW) vehicle with a 26-metre wing span capable of multiple payloads for long endurance missions over long range. This development will push this system in the class of the Global Hawk. It is evident from the operational data in Table 3 that the Heron's range, endurance and multiple payload capability put it in the strategic ISR category, and further upgradation will make it a very formidable system.

HARPY

TABLE 3.

	SEARCHER II	**HERMES 450**	**HERMES 1500**	**HERON**
Speed max/loiter	110 kts 60 kts	95 kts 50 kts	130 kts 80 kts	125 kts 70 kts
Endurance	18 h	20 h/ 28 h extended	26 h	50 h
Payload	100 kg	150 kg	300 kg	250 kg
Ceiling	20,000 ft	18,000 ft	33,000 ft	30,000 ft
Sensors	EO / IR, SAR	EO/IR, SAR Passive ESM and Com relay	EO/IR, SAR/ GMTI Passive ESM and Com relay	EO/IR, SAR/ GMTI, Maritime radar Passive ESM, Com relay
Radius	200 km	200 km	>200 km	1,000 km

Source: *Jane's Unmanned Aerial Vehicles and Targets*, <http://www.defense-update.com>.

Israeli thrust towards unmanned aviation developed mainly due to the requirements of its air force to reduce threats to its manned fighter aircraft from enemy air defences. Its Harpy UAV is a unique fire and forget armed UAV designed to detect, attack and destroy emitting radars of the adversaries' AD system up to 500 km range with its 32 kg high explosive. It has the capability to loiter for six hours during which it acquires the radar emissions and carries out a vertical dive attack. If the radar stops emitting, the UAV abandons attack and returns to loitering search mode till the end of its endurance when it is programmed for self-destruction. It straddles the gap between UAVs and loitering attack missiles. It is being improved further for visual identification and strike on the target to continue the attack even after the emitter stops radiating.

RESEARCH AND DEVELOPMENT

Airframe and Propulsion

Two diverging directions are being followed in airframe and propulsion systems. Strategic UAVs are being developed into ultra-long endurance systems capable of remaining aloft for months at a time with a host of sensors and payloads, including weapons for use on demand. Tactical UAVs are being downsized for operations in asymmetric confrontations involving urban terrain and guerrilla tactics. Propulsion technologies are aiming at lightweight, ultra-long endurance designs targeted for operations at low altitudes and also between 50,000 to 100,000 ft, using solar, electrical or fuel cell technologies. Lightweight heavy fuel engines using diesel rather than high octane fuels are being tested for use on smaller UAVs to simplify logistics. Acoustic and radar signature management is being addressed in the design phase to increase survivability. Small man-portable UAVs are increasingly

Propulsion technologies are aiming at light-weight, ultra-long endurance designs targeted for operations at low altitudes and also between 50,000 to 100,000 ft, using solar, electrical or fuel cell technologies.

using electric motors for quieter operations[38]. Man-portable systems are becoming prevalent around the world. Their payload capabilities are limited because of size but advanced technology has miniaturised sensors for use in the small payload bays. Small autopilot systems coupled with GPS are becoming standard navigation suites on these smaller systems. Ground control systems are also being reduced to the size of laptop computers with ability for network linking for field application of these smaller systems. The EO/IR equipped under development UAV of the USA, the Batcam, is tube launched with a 5 inch diameter and a span of 1.9 ft. It is planned to fly at 500 ft for 30 min at a gross take-off weight (TOW) of 1.5 lb including 0.5 lb payload.

Micro UAVs

Miniaturisation of computing, processing, avionics and propulsive systems is leading a revolution towards micro UAVs (MAV). Nanotechnology is being harnessed for quieter UAVs of the size of birds and insects for unobtrusive access anywhere to obtain real-time surveillance or sniffing for specific things like weapons and chemicals. Experimental flights have been conducted with small UAVs, a few inches in size. The progress in this direction will depend on advances in nanotechnology for miniaturised conformal sensors and propulsion systems.These are still experimental concepts and yet to reach the production stage but hold great potential for future asymmetric and urban warfare.

Radar and Imaging Payloads

Payloads research has become independent of the specific platform related development. Payloads developed for manned aircraft are being miniaturised for use on UAVs and similarly lightweight payloads developed for UAVs are benefiting manned aircraft by increasing the quantity of the payload. The reduction in size and weight of SAR has helped to increase the operational potential of UAVs. Earlier SAR payloads mounted on bigger UAVs weighed around 30 to 75 kg. The new mini SAR developed in Europe weighs about 4 kg and consumes less power. Advances in compressing data processing are increasing the onboard processing

38. The Raven of the USA and Skylark of Israel are two of the growing clan of small UAVs using electric propulsion.

capability, resulting in onboard data fusion from multiple sensors and transmission of a coherent picture to the command centres.

Data fusion technologies are helping in the work on coherent change detection[39] which operates in near real-time using SAR imagery to detect subtle changes, which are difficult and time consuming to detect, and are capable of generating important intelligence inputs, for example, detection of recent improvised explosive device (IED) insertions in the ground. LADAR (laser radar) is another scientific sensor payload being modified for the target acquisition role. It is used to create 3D imagery for terrain mapping which is being adapted for target identification and acquisition by matching the target of interest with known imagery. EO/IR sensor resolution is improving rapidly which is resulting in hi-resolution imagery from lower-cost lightweight systems. The resolution of imagery from EO systems is projected to double in the next five years and go up by six times by 2020. IR resolution will also improve but at a moderate rate[40]. Super sampling is another processing technique being developed to increase the resolution of an image by fusing together multiple images of the same area taken from different angles by the same sensor. Fusion of imagery for better resolution is also being progressed for SAR imagery under the inferometric SAR (IFSAR) and polarimetric SAR (PSAR) project. This system works on fusing together multiple SAR images of the same area taken by multiple UAVs flying close together to highlight differences that may not appear in individual SAR imagery.

The next big improvement in this direction will be implementation of the AESA multi-functional airborne radar, presently being developed under the MP-RTIP programme of the USA. This radar is projected to have multiple use capability which includes scanning and tracking of multiple ground and air targets simultaneously, high bandwidth communication, jamming and electronic attack of networks and terrain mapping. It has scalable architecture with capability to undertake multiple tasks simultaneously[41]. Research is progressing

39. A technique involving the collection and comparison of a pair of coherent synthetic aperture radar images from approximately the same geometry collected at two different times (before and after an event). It is capable of revealing minor changes in the imaged area such as those caused by vehicular movement (tyre tracks, tank tracks, etc.), mine or barrier emplacement.
40. As per the National Air and Space Intelligence Centre in USA, the resolution of EO system will improve to 10 megapixels by 2010 and 30 megapixels by 2020 from 5 megapixels presently. IR imagery resolution is projected to improve to 10 megapixels by 2020 from 2 megapixels of present systems.

in foliage penetration and ultra wide band sense through the wall radar for penetrating surveillance through camouflage.

The long-dwell capability of the UAV has a strong potential for exploitation as an airborne early warning (AEW) platform. Russia has already showcased the triangular shaped phased array radar on its Zond-1 UAV which has a reported endurance of more than 18 hours. Work is on in major UAV producing countries as the UAV-based AEW capability has immense operational value.

Command, Control and Navigation

Command and control is another major thrust area. Autonomy of the command and control function for reduced reliance on human operators is being pursued vigorously. Autonomy of operation will also impact the demand for secure bandwidth for data transfer and command and control functions. Most UAVs are capable of autonomous navigation and flying on planned flight paths. This navigation is generally dependant on GPS-fed inertial navigation systems. High risk of GPS jamming has led to the development of position measuring by comparing the aerial view with the digital terrain map. This technique is employed in the KZO UAV of Germany. Automatic take off/landing and recovery systems for UAVs have been successfully tested and are being incorporated on tactical UAVs. The demand for secure large bandwidth communication links for command and control and data transmission has become a major constraint in real-time sensor and vehicle exploitation. Increased autonomy and data processing by the UAV has the potential to address this problem to a certain extent and is being pursued. This requires very large scale memory and processing power for simulating the power of the human brain, which is a goal for the future. Though research is progressing on full autonomy, monitoring and optional control by human operators for affecting changes in mission profile or authorising weapon release is being retained as of now. A very high level of autonomy has been already demonstrated during the experimental

41. The RF array processor of AESA is composed of a grid of interconnected transmitter receiver modules, each with its own RF processing and control electronics. Size and performance of the radar can be moulded as per the size of platform by employing varying numbers of modules.

flying of the X-45. This UAV has displayed independent decision taking ability to abort landing after getting unsafe landing gear operation warning[42]. The ability to plan and execute a strike independently on the assigned target after weapon release authorisation has also been successfully tested on the X-45. Another concept being developed is the mutual interacting UAVs. This is projected for utilisation of small, low cost, autonomous UAVs in swarms. Deployment in swarms holds potential as it enjoys the advantage of the low cost multi-tasking option. The attrition will not be prohibitively costly due to the low cost of UAVs and payload. Multi-vehicle operation with inflight distributed control, multi-vehicle control by a single operator and autonomous low level flying in an area with surprise pop-up obstacles have been under experimental trials. Onboard health and usage monitoring (HUMS) technologies have been successfully incorporated and self-diagnostic techniques are being developed.

Armament

A large armament load comprising small, lightweight, self-navigating weapons with high lethality is the requirement for effective utilisation of UAVs for long dwell armed reconnaissance or strike roles. The low payload capacity of UAVs demands small size, and more effective weapon combinations to increase the number of weapons. Development of SDB for use on manned and unmanned aircraft is a step in that direction. Directed energy weapons (DEW) like intense microwaves or lasers are being talked about but these concepts are yet to develop to the stage for use on UAVs. The first experimental airborne laser system, mounted on a Boeing 747 is likely to undergo airborne trial in 2007. Present generation laser systems are producing 1 kw power per 5 kg weight whereas it needs to reach at least 5 kw per 1 kg of weight for getting a place on UAVs. Though work is progressing in the field of solid state laser and chemical laser, it will be a wild guess to predict the timeline for practical employment of airborne laser systems on UAVs in the near future.

These technologies are, however, very expensive and not yet mature

42. In 2005, an X-45A UAV autonomously abandoned approach after getting a false warning from the gear lock mechanism. It landed back after the problem was diagnosed and resolved. Francis, n. 35.

enough for implementation on medium and small UAVs which make up the bulk of UAVs operating globally. It may take decades before these experimental technologies mature to the level of mass scale adoption. However, the trends are clear, with indications of the deep penetration of UAVs in aviation in the future.

Trends

The progress of R&D in unmanned aviation technologies indicates some discernible trends.

(a) An increasing shift towards autonomy of flight operations, including takeoff and landing. This leads to safe recovery and operation by avoiding human inputs, a major cause of mishaps till date. Autonomy also reduces the strain on available bandwidth. This has implications for control of multiple UAVs by a single operator.

(b) A move towards full autonomy in mission execution with optional control. This implies autonomous operation of the UAV while retaining control for weapon release authority and optional human intervention in mission and flight operation. It will further reduce demand for dedicated bandwidth and also reduce the possibility of jamming as well as of intercept by minimising communication requirements.

(c) Preference for multi-role reconfigurable UAVs with modular architecture. This has economical implications along with technical support and logistical advantages.

(d) Increasing the capability of UAVs with payload capable of undertaking multiple roles simultaneously or single payload capable of switching roles in flight. This is to keep the weight under check to reduce the size of the UAV. The capability of using a single payload for multiple tasks has been tested on a Hunter UAV recently by inflight retasking of the same payload for either communication relay or SIGINT collection or as an EW tool[43].

(e) Convergence of sensors and payload with standoff capability on large high

43. In news report "Hunter Gather Information" by Aerospace Testing on April 01, 2006. Available in UVS International -News Flash at www.uvs-info.com-P7/33.

altitude long endurance UAVs.

(f) Increasing use of robust COTs technologies and components for keeping cost under check.

(g) Use of large numbers of low cost expendable autonomous UAVs operating in swarms in place of large multi-role costly UAVs with higher vulnerability is gaining ground and is being explored in research labs.

(h) Due to the high cost, high risk and long gestation period of R&D, existing successful platforms are being adopted and modified in international collaborative arrangements.

(i) Bio-sensors are being tested for use on small UAVs to detect anthrax and chemical agents.

(j) Reliability concerns are being addressed for vehicle safety due to costly systems and sensors.

(k) Collision avoidance systems are being developed to give UAVs capability to fly in civil air space.

(l) Surveillance and target tracking radars with air-to-air capability are being considered as a logical extension of reconnaissance, surveillance and target acquisition (RSTA) UAVs.

(m) Onboard processing is being improved for automatic target recognition, especially in the maritime environment. This is achieved by comparison with stored imagery.