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Review of Unmanned Aircraft System (UAS)

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***Abstract*- Unmanned Aircraft Systems (UAS) is an emerging technology with a tremendous potential to revolutionize warfare and to enable new civilian applications. It is integral part of future urban civil and military applications. It technologically matures enough to be integrated into civil society. The importance of UAS in scientific applications has been thoroughly demonstrated in recent years (DoD, 2010). Whatever missions are chosen for the UAS, their number and use will significantly increase in the future. UAS today play an increasing role in many public missions such as border surveillance, wildlife surveys, military training, weather monitoring, and local law enforcement. Challenges such as the lack of an on-board pilot to see and avoid other aircraft and the wide variation in unmanned aircraft missions and capabilities must be addressed in order to fully integrate UAS operations in the NAS in the Next Gen time frame.**

UAVs are better suited for dull, dirty, or dangerous missions than manned aircraft. UAS are mainly used for intelligence, surveillance and reconnaissance (ISR), border security, counter insurgency, attack and strike, target identification and designation, communications relay, electronic attack, law enforcement and security applications, environmental monitoring and agriculture, remote sensing, aerial mapping and meteorology. Although armed forces around the world continue to strongly invest in researching and developing technologies with the potential to advance the capabilities of UAS.

Keywords: UAS, UA, Command, Control and Communications (C3), UAS Autonomy

I. INTRODUCTION

In recent years, the term UAV has been replaced with the term UA which stands for Unmanned Aircraft. To emphasize that a UA is a part of a complete system including ground operator stations, launching mechanisms and so forth, the term Unmanned Aircraft System (UAS) has been introduced [14]. That system whose components includes the necessary equipment, network, and personnel to control an unmanned aircraft also called UAS [15].

II. UNMANNED AIRCRAFT SYSTEM

Unmanned Aircraft Systems (UAS), also commonly referred to as Unmanned Aerial Systems is defined as a system, whose components include the air vehicles and associated equipment that do not carry a human operator, but instead fly autonomously or are remotely piloted and all equipment, UAS must be considered in a systems context which includes the command, control and communications (C3) system, and personnel necessary to control the unmanned aircraft [8] [7] [3] [1] [2] [20] [27] [28] [20] [29] [30] [31] [33] [34].

Unmanned Aircraft system (UAS) has been used recently a lot in military applications as well as in civilian. Its importance and advantages in the search and rescue, real-time surveillance, reconnaissance operations, traffic monitoring, hazardous site inspection and range extension, recently it also used agriculture field. Moreover, UAS is suited for situations that are too dangerous and hazardous where direct monitoring of humanly not possible. In the unmanned aviation community UAS is growing field, In general terms, “UAS” describes “the entire system that includes aircraft, control stations and data links.” In reality, the system is far more complex organization following element [27] [28] [20] [29] [30] [31] [32] [3] [2] [33].

- Multiple aircraft
- Ground control shelters (C3)
- A mission planning shelter
- A launch and recovery shelter
- Ground data terminals
- Remote video terminals
- Modular mission payload modules
- Air data relays
- Miscellaneous launch, recovery, and ground support equipment [7]

III. HISTORY OF UAS

The UAV has been expanded in some cases to UAVS (Unmanned Aircraft Vehicle System). The FAA has adopted the acronym UAS (Unmanned Aircraft System) to reflect the fact that these complex systems include ground stations and other elements besides the actual air vehicles i.e. Unmanned Aircraft. “UAS” describes “the entire system that includes aircraft, control stations and data link” [20] [8] [6] [7] [3].

The first UAV was manufactured by the Americans Lawrence and Sperry in 1916 [2] [4] [33]. This is known as the beginning of “attitude control,” which came to be used for the automatic steering of an aircraft. They called their device the “aviation torpedo” and Lawrence and Sperry actually flew it a distance that exceeded 30 miles.

The development of UAVs began in earnest at the end of the 1950s, taking advantage of the Vietnam War or the cold war, with full-scale research and development continuing into the 1970s. UAV called Fire bee. After the Vietnam War, the U.S. and Israel began to develop smaller and cheaper UAVs. These were small aircraft that adopted small engines such as those used in motorcycles or snow mobiles. They carried video cameras and transmitted images to the operator’s location. It seems that the prototype of the present UAV can be found in this period. The U.S. put UAVs into practical use in the Gulf War in 1991, and UAVs for military applications developed quickly after this.

The most famous UAV for military use is the Predator; NASA was at the center of the research for civil use during this period. The most typical example from this time was the ERAST (Environmental Research Aircraft and Sensor Technology) project. It started in the 1990s, and was a synthetic research endeavor for a UAV that included the development of the technology needed to fly at high altitudes of up to 30,000 m, along with a prolonged flight technology, engine, sensor, etc. The aircraft that were developed in this project included Helios, Proteus, Altus, Pathfinder, etc., These were designed to carry out environmental measurements [2][16][17][33].

IV. UAS SYSTEMS

An unmanned aircraft system is a system comprised of three main features: the aircraft, the Ground Control Station (GCS or C3) and the operator.

- Unmanned Aircraft
- Command and Control Link/ Data Link
- Ground Control Station (GCS)

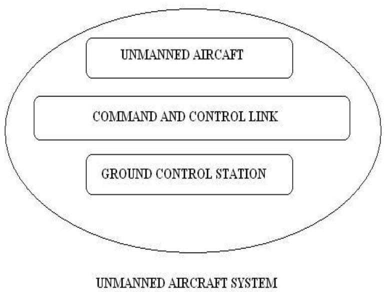

Fig-1:

Unmanned Aircraft System Model

The UA is an acronym for Unmanned Aircraft, which is an aircraft with no pilot on board. UA can be remote controlled aircraft (e.g. flown by a pilot at a ground control station) or can fly autonomously based on pre-programmed flight plans or more complex dynamic automation systems and can carry a lethal or non- lethal payload (These payloads can be high and low resolution cameras/video cameras, day and night reconnaissance equipment, warfare machinery (ESM, ECM, ECCM) weapons and generally any equipment required for the mission the UAV is designed for)[20][8][6][7][3][25][27][28][20][29][30][31][33][34].

A. Classification of Unmanned Aircraft:

A powered vehicle that does not carry a human operator, can be operated autonomously or remotely, can be expendable or recoverable, and can carry a lethal or nonlethal payload. Ballistic or semi-ballistic vehicles, cruise missiles, artillery projectiles, torpedoes, mines, satellites, and unattended sensors (with no form of propulsion) are not considered unmanned vehicles [35]. But as per increasing use in military area of UA, in battle field it may be possible above element is a component of UA. The UAV or UAVs (aircraft component(s)) and the required flight control and operating system which includes the control station(s), communication links, data terminal(s), launch and recovery systems, ground support equipment and air traffic control interface. Recently as per increasing use of UAS in Military, Civil and Other areas for different special purpose task. Significant efforts have been devoted to increasing the flight endurance and payload of UA, resulting in various UA configurations with different sizes, endurance levels, and capabilities. Here, classify UA according to their characteristics (aerodynamic configuration, size, etc.). UA platforms typically fall into one of the following four categories: [2] [7] [6]

Fixed-wing UA: which refer to unmanned airplanes (with wings) that require a runway to take-off and land, or catapult launching these generally have long endurance and can fly at high cruising speeds.

Rotary-wing UA: also called rotorcraft UAVs or vertical take-off and landing (VTOL) UAVs, which have the advantages of hovering capability and high maneuverability. These capabilities are useful for many robotic missions, especially in civilian applications. A rotorcraft UAV may have different configurations, with main and tail rotors (conventional helicopter), coaxial rotors, tandem rotors; multi-rotors, etc.

Blimps: such as balloons and airships, which are lighter than air and have long endurance, fly at low speeds, and generally are large sized.

Flapping-wing UA: which have flexible and/or morphing small wings inspired by birds and flying insects. There are also some other hybrid configurations or convertible configurations, which can take-off vertically and tilt their rotors or body and fly like airplanes, such as the Bell Eagle Eye UAV. Another criterion used at present to differentiate between aircraft is size and endurance [2] [4] [31].

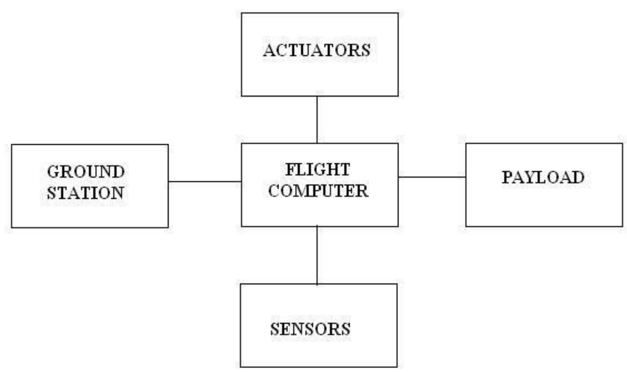

Fig-2: Basic UAV Avionics Architecture [34].

Flight Computer/ aircraft control system: Used to fly the UAV. Either a two-way data link (radio) for remote control or an onboard computer (generally with GPS navigation) connected to the aircraft control system. [21] flight control and operating system which includes the control station(s), communication links, data terminal(s), launch and recovery systems, ground support equipment and air traffic control interface.

Actuators:

Payload: Payloads can be high and low resolution cameras/video cameras, day and night reconnaissance equipment, high-power radar, gyro-stabilised, electro-optical, signals, meteorological, chem-bio, relay (communications, navigation signals),warfare machinery (ESM, ECM, ECCM) weapons , cargo (leaflets, supplies), and generally any equipment required for the mission the UAV is designed. The desire for endurance in many UA demands a high fuel fraction, resulting in a corresponding low payload fraction, typically 10 to 20 percent of gross weight [25] [29] [30].

Sensors: Sensor is used to provide basic functionality which is the ability to maintain flight without human input, radar, photo or video camera, IR scanners or ELINT are most common. Sensors may include a (laser) target designator to provide guidance for stand-off guided missiles and shells. Requirements for sensing payloads on UA extend not just to intelligence collection and reconnaissance surveillance and target acquisition to provide operations support, but also to weapons delivery, due to their reliance on detecting and identifying the target to meet the rules of engagement (ROE) constraints and to improve aim point accuracy [14] [21] [30].

Navigation sensors and microprocessors: Sensors now represent one of the single largest cost items in an unmanned aircraft and are necessary for navigation and mission achievement. Processors allow UAVs to fly entire missions autonomously with little or no human intervention [2].

Aircraft onboard intelligence (guidance, navigation, and control): The intelligence that can be "packed" into a UA is directly related to how complicated a task that it can handle, and inversely related to the amount of oversight required by human operators. More work needs to be done to mature these technologies in the near term to show their utility and reliability. The reader can refer to for more details on forecasting trends in these technologies over the coming decades [2].

Communication systems (data link) (Air data terminal): The principal issues of communication technologies are flexibility, adaptability, security, and cognitive controllability of the bandwidth, frequency, and information/data flows [2]. A UAS data link typically consists of an RF transmitter and a receiver, an antenna, and modems to ink these parts with the sensor systems. For UAS, data links serve three important functions:

(1) Uplinks from the ground station and/or a satellite to send control data to the UAV

(2) Downlinks from the UAV to send data from the onboard sensors and telemetry system to the ground station

(3) A means for allowing measurement of the azimuth and range from the ground station and satellite to the UAV to maintain good communications between them.

Efforts to standardize data links have resulted in the use of the common data link (CDL), typically a full duplex, wideband data link when used by UAS usually jam resistant and secure. These links connect the ground station with the UAV via direct, point-to-point links or use satellite communications (SATCOM) [10].

Control Types

The central tenet of the unmanned aircraft system is that the operator is removed from the cockpit; therefore, control of the aircraft must take place by other means. There are three forms of control that an operator may exert over the aircraft

- Ground-control or remote piloting;
- Semi-autonomous; and
- Autonomous.

The dependence of the machine on ground control not by the technological aspects of how the ground controller communicates with and controls the machine (Lazarski)

Ground control: Ground-controlled UA also called Remotely Piloted Vehicles ("RPVs"), require constant input from the operator. In essence, RPVs are "sophisticated radio-controlled aircraft that use the same basic techniques that are familiar to the R/C hobbyist". There are very few modern UA that are purely remotely piloted. "In the 1980's and early 1990's, systems such as Pointer and Sky Owl began employing both remote control techniques and programmable guidance systems (a basic form of autonomy). Thus the trend in unmanned aviation circles has been towards more autonomous systems. [7][27][28][29]

Semi-autonomous: The use of guidance systems is now commonplace and semi-autonomous flight can be defined as requiring "ground input during critical portions of the flight such as take-off, landing, weapons employment, and some evasive manoeuvres" . The operator must assume full control of the aircraft during pre-flight, take-off, landing, and when operating near base, but once airborne an autopilot function can be engaged and the aircraft will follow a set of preprogrammed waypoints. The operator is responsible for the UA throughout the operation, however, and can assume control at any time. [7][27][28][29]

Fully autonomous: Fully autonomous capability lies at the other end of the spectrum. In theory, autonomous flight requires no human input in order to carry out an objective following the decision to take-off. An autonomous UA is able to monitor and assess its health, status and configuration; and command and control assets onboard the vehicle within its programmed limitations. "A sophisticated autopilot, allowing it to "fly itself" on programmed flight paths without [human] interference for almost all the mission". "Without an operator doing anything more than monitoring its systems". Thus, under autonomous control, the reality is that the on-board computer is in control not a human being. [7][27][28][29]

Ground Control Station (GCS) or C3

An area where UAS have their own technology is that of telecommunications, guidance and control technology, solid-state gyros and sensors have made the platforms more reliable in terms of flight control. Modern telecommunication technology can uplink flight and mission commands to the aircraft at very long rates and over large distances [1] [3][7].

Ground Station Command, Control, and Communications (C3): There are several key aspects of the off-board C3 infrastructure that are being addressed, such as man–machine interfaces, multi-aircraft C3, target identification, downsizing ground equipment, voice control, etc. Advancing the state of the art in all of the Areas discussed above will allow a single person to control multiple aircraft. UAS under his control, to ensure the safe and efficient conduct of flying operations. The command and control function is accomplished by a combination of planning, personnel, equipment, communications, navigation and technical functions and procedures [2] [3] [39]

C3 system model

A C3 system model shown in Fig-3 UAS operations, aircraft may operate within radio frequency line-of- sight, or beyond line-of-sight. Technologies and operating procedures related to command, control, and communication of UAS are divided into one of these two categories.

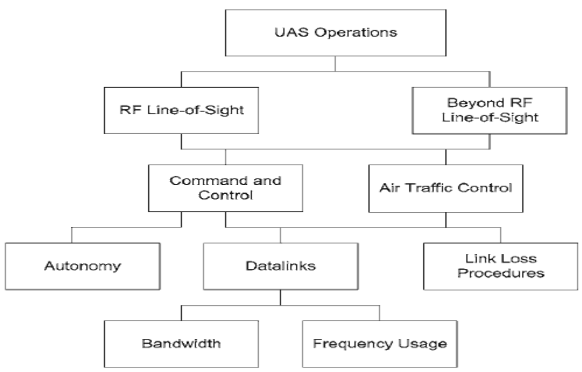

Fig-2: C3 system model [39]

Under each category of RF LOS and BLOS, UAS technical issues may be divided into two categories: Command and Control (C2) and Air Traffic Control (ATC).Under C2 and ATC, the various data links are examined including their respective frequency and data rates. The current link loss procedures are enumerated [39].

BLOS operations subset of LOS operations: It is important to note that BLOS UAS do contain some LOS technologies. Fig-4 illustrates the overlap between these operating conditions and the class of UAS that can operate within these areas. The line-of-sight section include all aircraft, but beyond the line-of-sight section include only medium and high-endurance UAS capable of operating beyond the RF line-of- sight of the pilot-in-command [39].

Fig-4: BLOS operations subset of LOS operations [39]

RF Line-of-Sight C3 Technologies and Operations: Line-of-sight operation may be divided among three classes of unmanned aircraft, which are low endurance, medium endurance, and high endurance. The first class operates almost entirely in line-of-sight [39].

Beyond RF Line-of-Sight C3 Technologies and Operations: The beyond line-of-sight UAS covers primarily high endurance UAS, but a few medium endurance UAS that operate beyond line-of-sight [39]. Satellite-based communications (SATCOM) are used in beyond line-of-sight command and control communication with unmanned aircraft.

Most commonly used frequency bands for UAS: These communications are done primarily through the use of RF applications, usually, satellite communication links in UAS are used either in LOS (for military applications) or in BLOS mode. The most common frequency bands of this type of links are: [8] [10]

- Ku band: this band has been historically used for high speed links. Due to its short wavelengths and high frequency, this band suffers from more propagation losses. Yet it is also able to trespass most obstacles thus conveying great deals of data.
- K band: possesses a large frequency range which conveys large amounts of data. As a main drawback it should be mentioned that it requires powerful transmitters and it is sensitive to environmental interferences.
- S, L bands: they do not allow data links with transmission speeds above 500 kbps. Their large wavelength signals are able to penetrate into terrestrial infrastructures and the transmitter require less power than in K band.
- C band: it requires a relatively large transmission and reception antenna.
- X band: reserved for military use.

Band	Frequency
HF	3-30 MHz
VHF	30-300 MHz
UHF	300-1000 MHz
L	1-2 GHz (General) 950-1450 MHz (IEEE)
S	2-4 GHz
C	4-8 GHz
X	8-12 GHz
Ku	12-18 GHz
K	18-26.5 GHz
Ka	26.5-40 GHz

Table-1: Frequency Band [26].

Network- centric Communications: There are several areas of networking technology development that should be identified as critical to the migration path of UAS and their ability to provide network services, whether they are transit networking or stub networking platforms. The networked communications capabilities need to migrate to provide capacity, stability, reliability and rich connectivity/interoperability options. The following technologies are essential to this development:

- High Capacity Directional Data links
- High capacity routers with large processing capacity - Ruggedized IP enabled Wideband Routers
- Modular and Programmable Router Architecture
- Well-known and Standardized Protocols and Interfaces
- Mobile Ad-hoc quasi-stable mesh - requirement to manage topology
- Interdependent relationships between the following:
- Switching/Routing
- Topology Management
- QoS – packet level
- Hierarchical management
- Multiple link interfaces and types per platform
- Gateway functionality on platforms (legacy, disparate networks)
- Embedded INFOSEC/network security
- Performance Enhancing Proxies

While these large stable UAS platforms are ideal for providing theater backbone services, smaller UAS may provide similar networking capability and services on a smaller scale. Additionally, the same networking functions that enable UAS platforms to provide network-centric services also allow the UAS to take advantage of networking to augment their capabilities [30].

MANET: A flexible wireless network applicable to a heterogeneous UAS team (or fleet) that does not require any infrastructure to operate. This kind of infrastructure-less network oriented to collaboration is known as Mobile Ad-hoc Networks (MANET). MANETs are self-organized networks where the different wireless links (nodes) cooperate to provide network connectivity. In MANETS, every node acts as a communications repeater (or relay), forwarding information to the destination node. It is foreseen that during the next years, these networks will be extensively used in civil and military applications involving communication equipment for collaborative missions [8] [40] [41] [42] [43] [44]

Security Issues of UAS C3 Technology and Operations: Data link spoofing, hijacking, and jamming are major security issue facing UAS C2 and ATC communications. UAS are different than conventional aircraft from the point of "immediate control" of the aircraft. Pilot in "immediate control" means in an adverse event, the pilot can fly without putting aircraft or other aircraft in the immediate vicinity at risk of collision. In case of UAS, there is a medium between pilot at the ground control station and aircraft which is not the case with conventional aircraft. This medium being the data link, it is easily susceptible to threats mentioned previously. A hacker can create false UAS signals, jam the data link or even hi-jack the data link and take the control of UA. This issue must be addressed while picking the appropriate data link for future UAS C2 and ATC communication, as data links are vital to the safety and seamless functioning of the UAS. In order to make C2 and ATC communication foolproof, security features can be built into the system. For example, one approach is for the aircraft to acknowledge or echo all commands it receives. This will ensure the pilot-in-command that all commands sent are received and acknowledged. Such an approach will also notify the pilot in command if the aircraft receives commands from an unauthorized entity. The military uses secured data links like CDL and Link with built-in validating functions. No such permanent solution is available for civilian market and the area must be explored [39].

V. UAS AUTONOMY

UAS may be Automated, autonomous, semi-autonomous, and piloted remotely or a mixture of those capabilities [8] A minimal autopilot system includes attitude sensors and onboard processor. Due to the high nonlinearities of the air plane dynamics, a lot of advanced control techniques, such as PID control, neural network (NN), fuzzy logic (FL), sliding mode control, and $H\infty$ control, have been used in autopilot systems to guarantee a smooth desirable trajectory navigation. Nowadays, technological advances in wireless networks and micro electromechanical systems (MEMS) make it possible to use inexpensive micro autopilots [20] "Autonomy is the ability of an agent to carry out a mission in an independent fashion without requiring human intervention" [8]. Decision-making by Autonomous Systems, Delegation to an Autonomous System, Sub-systems and Autonomous Capability, Learning Systems type of autonomous system[3].

Advances in autonomous UAS technologies: among these technologies, some apply equally (similar) to manned aircraft such as airframe, propulsion system, aircraft structures, etc. Other technologies are specific to UAS to enable unmanned flight and autonomous behavior(Observe, Orient, Decide, Act [8]). Among these technologies, navigation sensors and avionics, communication systems, C3 infrastructures (command, control, and communication), and onboard autonomous capabilities. The scope of this paper is more on the onboard autonomy technologies for UAS which can be divided into three main categories: 1) Guidance, Navigation, and 3) Control. The final paper will discuss latest autonomy technologies and innovations and present progress and milestones in GNC areas.[4]

An industry objective is that eventually autonomous UAS will be able to operate without human intervention across all flight sectors:

- Ground manoeuvring, including ground collision avoidance;
- Take-off and climb;
- En-route;
- Descent and landing;
- Ground operation at the destination; and
- Handling of emergencies in any of these sectors [3].

Unmanned Aircraft Systems Roadmap 2005-2030 predicts future levels of autonomy with reference to ten Autonomous Control Levels:

1. Remotely guided
2. Real-time health/diagnosis
3. Adapt to failures & flight conditions
4. Onboard route re-plan
5. Group co-ordination
6. Group tactical re-plan
7. Group tactical goals
8. Distributed control
9. Group strategic goals
10. Fully autonomous [12]

Autonomy of the UAS and human operator workload. The core components of autonomy are flight control, navigation and guidance. Higher levels of autonomy, which reduce operator workload, include (in increasing order) sense-and-avoid, fault-monitoring, intelligent flight planning and reconfiguration. [19][34][27][28][29][30][33]

Automated System: In the unmanned aircraft context, an automated or automatic system is one that, in response to inputs from one or more sensors, is programmed to logically follow a pre-defined set of rules in order to provide an outcome. Knowing the set of rules under which it is operating means that its output is predictable.

Autonomous System: An autonomous system is capable of understanding higher level intent and direction. From this understanding and its perception of its environment, such a system is able to take appropriate action to bring about a desired state. It is capable of deciding a course of action, from a number of alternatives, without depending on human oversight and control, although these may still be present. Although the overall activity of an autonomous unmanned aircraft will be predictable, individual actions may not be.

Navigation: The UAV must have a means of finding its position at any point on the earth at any time. This results in the requirement for a robust, high accuracy, highly available and high integrity navigation system. The obvious choice for such a navigation system is GPS, however even GPS must be augmented with additional sensors to ensure the robustness and integrity of the navigation solution.

Guidance and Flight Control: The UAV must generate the steering commands and subsequent control surface deflections to adequately find its way along the chosen flight path. These calculations are relatively simple compared with the flight planning and navigation algorithms, however ideally require the use of floating-point calculations.

Sense-and-Avoid: One of the biggest limitations to the widespread use of unmanned vehicles in civilian airspace has been the Sense-and-Avoid problem [1]. In manned civilian aviation, See and-Avoid is the primary mechanism by which piloted aircraft avoid collisions with each other. Obviously this is impractical for widespread use of unmanned vehicles, so they must achieve an equivalent level of safety to that of manned aircraft operations. There is currently a large amount of research being conducted on the UAV Sense and Avoid problem. Active solutions include the use of radar or TCAS to detect collision threats, however this requires high amounts of electrical power, and are quite heavy (in the order of 20kg or more). Passive solutions include the use of machine vision, which reduces the power requirement to a degree but, however, has a high computational requirement.

Fault Monitoring: To ensure the integrity of the UAV's systems, fault monitoring must be continually conducted on flight and mission critical systems. Fault monitoring ensures that undetected system faults will not lead to a catastrophic failure of the aircraft's systems which could lead to human casualties on the ground.

Intelligent Flight Planning: The UAV system must have the capability to plan and re-plan its own flight path. This results in the requirement for a high level computing environment where flight planning algorithms can be run. The flight planning operation requires knowledge of the UAV's surroundings; including airspace, terrain, other traffic, weather, restricted areas and obstacles. The UAV must plan the optimal route for its mission, considering the local environment, flight time and fuel usage. In the event of system faults, the UAV must have the capability to reconfigure itself and re-plan its flight path in a fail-safe manner. The flight planning requirements result in a significant requirement for memory and floating point operation performance.

Payload: A civilian UAV is designed to perform a particular mission at a lower cost or impact than a manned aircraft equivalent. The payload is the equipment installed by the customer that performs a specific task. The payload will require at least a space, weight and power allocation. However, certain payloads may also require access to UAV system data, such as

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position, airspeed, or altitude. Thus, a mechanism must exist to provide UAV data to the payload in a manner such that the failure of the payload cannot impact the safety of the UAV's own systems (for example denying access to the data-bus by grounding signal lines)

Operating System and Software Considerations: The Operating System (OS) Application Programming Interface (API) is a very important consideration, not only from the point of view of execution, but also in the ease of system development. Due to the time critical nature of flight control, high reliability and real-time execution is mandatory. The Portable Operating System Interface (POSIX) IEEE 1003.1 is the preferred operating system interface standard since it is widely supported, and allows easy porting of applications between the various flavors of Unix, Linux and QNX. QNX is currently used widely in the QUAV group for desktop and embedded computing requirements as it provides an excellent feature set and performance. The advantages of QNX are fully evident with the process of porting applications from Linux to QNX being very straight forward, in many cases simply requiring a re-compile under the new OS.[34]

Automated recovery: Since physical pilot control is not possible, the UAS must have "numerous fail safes" in place in case of link loss. The most desirable failsafe is for the UAS to execute an automated recovery. The USAF Strategic Vision suggests that in the event that command and control links have been completely severed between an unmanned system and the command centre, the RPA or UAS should be pre-programmed either to attempt for some fixed period of time to re-establish communications, to execute a fully automated egress from the battle space, or to independently complete the mission. A similar procedure is applicable to civil UAS [7].

VI. UNMANNED AIRCRAFT SYSTEM CLASSIFICATION

There currently is no widely accepted common classification of UAS, due to the wide variety of capabilities, size, and operating characteristics of different systems. Most UAS are described in terms of maximum gross take-off weight (UA with Payload), Endurance, and Altitude , Radios of operational area, Purpose of use, Task which is perform by UAS (dull, dirty, dangerous) and as per the requirement of operation we can classified UAS.

High Altitude: UAVs able to fly within a range Over 60,000 ft

Medium Altitude: UAVs able to fly within a range of 18,000 – 60,000 ft

Low Altitude: UAVs able to fly within a range o Up to 18,000 ft

Very Low Altitude: UAVs able to fly within a range below 1,000 ft

Endurance: which is vehicles able to operate in a range of more than 500 km, or that can stay in the air for more than 20 hrs. These are considered to be the most sophisticated of the UAV family due to their high capabilities. They can be distinguished from other systems by their large dimensions and their high capabilities. [35]

Category	Weight of UAV	Normal Operating Altitude	Radius of Mission	Endurance	Altitude	Normal Employment	Typical Use
MICRO	< 2 kg	Up to 200ft AGL	5 km (LOS)	A few hours	Very Low Altitude	Tactical Platoon(Single operator)	Reconnaissance, inspection, surveillance
MINI	2-20 kg	Up to 3000ft AGL	25 km (LOS)	Up to 2 days	Low Altitude	Tactical Sub-Unit(manual launch)	Surveillance, data gathering
SMALL	20 -150 kg	Up to 5000ft AGL	50 km (LOS)	Up to 2 days	Low Altitude	Tactical Unit(employs launch system)	Surveillance, data gathering
TACTICAL	150-600 kg	Up to 10,000ft AGL	200 km (LOS)	Up to 2 days	Low Altitude	Tactical Formation	Surveillance, data gathering
MALE	> 600 kg	Up to 45,000ft AGL	Unlimited (BLOS)	Days/ weeks	Medium Altitude	Operational/ Theatre	Surveillance, cargo transportation
HALE	> 600 kg	Up to 65,000ft AGL	Unlimited (BLOS)	Days/ weeks	High Altitude	Strategic/ National	Surveillance, data gathering, signal relay
STRIKE/ COMBAT	> 600 kg	Up to 65,000ft AGL	Unlimited (BLOS)	Days/ weeks	High Altitude	Strategic/ National	Surveillance, data gathering, signal relay

Table-2: UAS Classification of Categories wise [3], [7], [9], [13], [16], [17], [25], [27], [28], [30], [35],[36],[37].

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Category	UAS/ RPV	Weight of UAV	Normal Operating Altitude	Radius of Mission	Endurance	Altitude	Typical Use
SMALL	Kapothaka (RPV)	130 kg (AUW)	Low	(LOS)	90 min	Low Altitude	Surveillance/Reconnaissance
	Ulka	360 kg	100 m to 9 km	70 km (LOS)	5 min (max.)	Low Altitude	Surveillance/Reconnaissance
	Nishant	370 kg	3600 m AMSL	175 km (160 km) (LOS)	4 ½ h	Low Altitude	Surveillance, day/night reconnaissance gathering
TACTICAL	Lakshya	700 kg	9000 m (clean); 6000 m (tow)	100 km (LOS)	45 min	Low Altitude	Surveillance/Reconnaissance
MALE	Rustom	750* kg	25000 ft AGL	Upto250km (LOS)	12-15h	Medium Altitude	Surveillance/Reconnaissance
	Rustom-H (Future Project)	750 * kg	Up to up to 30,000 AGL	250 km And up to 350km (LOS)	up to 35 h	Medium Altitude	Surveillance/Reconnaissance
STRIKE/ COMBAT	Auro (IUASV)		30,000 ft with payloads	Expected to draw Several Evolutionary Technologies from the Rustom-2			

Table-3: INDIAN UAS/ RPV Classification of Categories wise [31].

UAS Types

- Target and decoy - providing ground and aerial gunnery a target that simulates an enemy aircraft or missile
- Reconnaissance - providing battlefield intelligence
- Combat - providing attack capability for high-risk missions
- Research and development-used to further develop UAV technologies to be integrated into field deployed UAV aircraft
- Civil and Commercial UAVs - UAVs specifically designed for civil and commercial applications.

Categories of UAS

HALE: High altitude long endurance. Over 15 000 m altitude and 24+ hr endurance They carry out extremely long-range (trans-global) reconnaissance and surveillance and increasingly are being armed. They are usually operated by Air Forces from fixed bases.

MALE: Medium altitude long endurance. 5000–15 000 m altitude and 24 hr endurance. Their roles are similar to the HALE systems but generally operate at somewhat shorter ranges, but still in excess of 500 km. and from fixed bases.

TUAV: Medium Range or Tactical UAV with range of order between 100 and 300 km. These air vehicles are smaller and operated within simpler systems than are HALE or MALE and are operated also by land and naval forces.

Close-Range UAV used by mobile army battle groups, for other military/naval operations and for diverse civilian purposes. They usually operate at ranges of up to about 100 km and have probably the most prolific of uses in both fields, including roles as diverse as reconnaissance, target designation, NBC monitoring, airfield security, ship-to-shore surveillance, power-line inspection, crop-spraying and traffic monitoring, etc.

MUAV or Mini UAV: Relates to UAV of below a certain mass (yet to be defined) probably below 20 kg, but not as small as the MAV, capable of being hand-launched and operating at ranges of up to about 30 km. These are, again, used by mobile battle groups and particularly for diverse civilian purposes.

Micro UAV or MAV: The MAV was originally defined as a UAV having a wing-span no greater than 150 mm. This has now been somewhat relaxed but the MAV is principally required for operations in urban environments, particularly within buildings. It is required tofly slowly, and preferably to hover and to 'perch' – i.e. to be able to stop and to sit on a wall or post. To meet this challenge, research is being conducted into some less conventional configurations such as flapping wing aircraft. MAV are generally expected to be launched by hand and therefore winged versions have very low wing loadings which must make them very vulnerable to atmospheric turbulence. All types are likely to have problems in precipitation.

NAV (Nano Air Vehicles): These are proposed to be of the size of sycamore seeds and used in swarms for purposes such as radar confusion or conceivably, if camera, propulsion and control sub-systems can be made small enough, for ultra-short range surveillance.

Research: developed for specific investigations, typically with no production intent.

Some of these categories possibly up to the TUAV in size can be fulfilled using rotary wing aircraft, and are often referred to by the term remotely piloted helicopter (RPH). RPH, remotely piloted helicopter or VTUAV, vertical take-off UAV. If an air vehicle is capable of vertical take-off it will usually be capable also of a vertical landing, and what can be sometimes of even greater operational importance, hover flight during a mission. Rotary wing aircraft are also less susceptible to air turbulence compared with fixed-wing aircraft of low wing-loading. UCAV and UCAR. Development is also proceeding towards specialist armed fixed-wing UAV which may launch weapons or even take part in air-to-air combat. These are given the initials UCAV for unmanned combat air vehicle. Armed rotorcraft are also in development and these are known as UCAR for Unmanned Combat Rotorcraft [21] [29].

VII. APPLICATION OF UAS

Currently, the main UAV applications are defense related and the main investments are driven by future military scenarios. Most military unmanned aircraft systems are primarily used for Intelligence, Surveillance and Reconnaissance (ISR) patrols and strikes. It also use for Chemical, Biological, Radiological and Nuclear (CBRN) detection, or simply those tasks considered too dangerous or politically challenging for manned aircraft to undertake. UAS are preferred over manned aircraft not only because of downsizing risk and increasing confidence in mission success avoiding at the same time the human cost of losing lives if the mission is unsuccessful, but also because unmanned vehicles have better and sustained alertness over humans during dull operations. Furthermore, many other technological, economic, and political factors have encouraged the development and operation of UAS. Unmanned aircraft operations have been under the scope of the Japanese Ministry of Agriculture, Forest and Fisheries and its affiliated association, the Japanese Agriculture Aviation Association [2][3][4][19][25][27][28][29][30][31][34] [33] [35][45].

Tasks for Unmanned Aircraft: UAS are better suited for dull, dirty, or dangerous missions than manned aircraft [3][27][28][29][30][31][34] [33] [35][37].

Dull: Operations that require more than 30- or 40-h missions are best carried out using UAS, Low workload, low intensity tasks are ideally suited to unmanned aircraft . Such tasks can be simply automated, often only requiring human oversight rather than direct and continuous control. There is a long list of tasks that could be included in this category such as: pattern of life surveillance tasks over fixed locations or in support of littoral manoeuvre a range of electronic warfare tasks, acting as a communications relay; and as an air-to-air refueling tanker. However, some of these tasks may themselves generate more complex or time-sensitive tasks (such as the identification of a fleeting high value target) that may not easily be prosecuted by a simple, single task platform.

Dirty: Unmanned aircraft are an ideal choice when operations are required in environments that would be hostile to a manned aircraft or its crew. (as happened in 1946–1948,UAS fly into nuclear clouds immediately after bomb detonation, a mission that is clearly dangerous to human crews and threatens human lives.) For instance, airborne sampling or observation missions related to CBRN would be ideally suited to unmanned aircraft. Sensors could be fitted to a range of types; for example, a small man-portable system for local tactical use, or large aircraft-sized systems for global monitoring. In the civilian sector, small unmanned aircraft are already used by some fire brigades for reconnoitring fires in inaccessible Locations or where smoke and flame would make human presence hazardous.

Dangerous: Operations like reconnaissance over enemy territory may result in loss of human lives, thus UAS are preferred. The level of risk of a particular operation may be too high to merit the involvement of human aircrew or soldiers on the ground. This may be because of a high ground-to-air threat and there are a number of tasks where unmanned aircraft may participate in the suppression of an integrated air defence system. In such a scenario, multiple, cheap unmanned aircraft can be used sacrificially to swamp enemy detection and command and control systems or to force an enemy to expend large numbers of missiles. Unmanned aircraft can potentially replace several dangerous ground tasks, such as convoying of tactical supplies and sweeping for improvised explosive devices.

Military Applications: UAVs are capable of performing a variety of missions supporting military and intelligence purposes. The list below presents the military applications that UAVs have served up to now.

- Reconnaissance Surveillance and Target Acquisition (RSTA).
- Surveillance for peacetime and combat Synthetic Aperture Radar (SAR).
- Deception operations.
- Maritime operations (Naval fire support, over the horizon targeting, anti-ship missile defence, ship classification).
- Electronic Warfare (EW) and SIGINT (SIGnals INTelligence).
- Special and psyops.
- Meteorology missions.
- Route and landing reconnaissance support.

- Adjustment of indirect fire and Close Air Support (CAS).
- Battle Damage Assessment (BDA).
- Radio and data relay
- Nuclear cloud surveillance

Military roles according to arm and forces [29]

Navy

- Shadowing enemy fleets
- Decoying missiles by the emission of artificial signatures
- Electronic intelligence
- Relaying radio signals
- Protection of ports from offshore attack
- Placement and monitoring of sonar buoys and possibly other forms of anti-submarine
- warfare

Army

- Reconnaissance
- Surveillance of enemy activity
- Monitoring of nuclear, biological or chemical (NBC) contamination
- Electronic intelligence
- Target designation and monitoring
- Location and destruction of land mines

Air Force

- Long-range, high-altitude surveillance
- Radar system jamming and destruction
- Electronic intelligence
- Airfield base security
- Airfield damage assessment
- Elimination of unexploded bombs

Civil Applications: Today, the civilian markets for UAVs are still emerging. However, the expectations for the market growth of civil and commercial UAVs are very high. Potential civil applications of UAVs are Inspection of terrain, pipelines, utilities, buildings, coast guards, border patrol organizations, rescue teams, police, etc.

- Policing duties(civil)
- Traffic spotting(civil)
- Fisheries protection(civil)
- Pipeline survey(civil)
- Sports events film coverage(civil)
- Agricultural operations(civil)
- Power line survey(civil)
- Aerial photography(civil)
- Border patrol(civil)
- Surveillance of coastal borders, road traffic, etc. (civil)
- Disaster and crisis management search and rescue. (civil)
- Environmental monitoring. (civil)
- Agriculture and forestry. (civil)
- Fire fighting. (civil)
- Communications relay and remote sensing.
- Aerial mapping and meteorology.
- Research by university laboratories. (civil)
- Communications relay. (civil)
- Law enforcement(civil)
- And many other applications. (civil)

VIII. FUTURE IMPLEMENTATION AND ADVANCEMENT

The next generation of UAVs will execute more complex missions such as air combat; target detection, recognition, and destruction; strike/suppression of an enemy's air defense; electronic attack; network node/communications relay; aerial delivery/ resupply; anti-surface ship warfare; anti-submarine warfare; mine warfare; ship to objective maneuvers; offensive and defensive counter air; and airlift.

Potential changes include the creation of an information management system to exchange information among Air Traffic Management users and providers, the introduction of 4-D navigation at high altitude, and the development of alternative separation procedures [24].

Autonomy technology that will become important to future UAS development falls under the following categories:[3][4][7][12][19][23][27][28][29][30][33]

- **Sensor fusion:** Combining information from different sensors for use on board the vehicle
- **Communications:** Handling communication and coordination between multiple agents in the presence of incomplete and imperfect information
- **Motion planning (also called Path planning):** Determining an optimal path for vehicle to go while meeting certain objectives and constraints, such as obstacles
- **Trajectory Generation:** Determining an optimal control maneuver to take to follow a given path or to go from one location to another
- **Task Allocation and Scheduling:** Determining the optimal distribution of tasks amongst a group of agents, with time and equipment constraints
- **Cooperative Tactics:** Formulating an optimal sequence and spatial distribution of activities between agents in order to maximize chance of success in any given mission scenario.

IMM: Intelligent Mission Management important to future UAS development

Collaborative and Coordinated System (CCS): An environment providing mission operators and scientists with a
situation awareness capability for facilitating UAV operations. This will be accomplished by providing an enhanced
derivative of the Collaborative Information Portal (CIP) developed for the Mars Exploration Rover mission. The
resulting system will provide personnel participating in the UAV mission with a unified interface to the payload

systems, internal UAV state (including the state of its autonomous controllers), external data sets, personnel, and other
sources of information necessary for the accomplishment of that mission. This Collaborative Decision Environment
(CDE) will afford the means to visualize, observe and interpret data obtained by the payload; to visualize, observe and
interpret mission-related data from sources external to the UAV system; to direct the payload systems (and indirectly, the UAV); to communicate with other team members; and to integrate sensing goals into mission planning.[23]

Intelligent Autonomous Architecture (IAA): A combination of on-board and ground-based automated systems for
controlling the vehicle and its payload. The onboard autonomous executive will execute the flight plan, along with
performing other basic tasks associated with flying the vehicle, including payload-directed flight. Capabilities to be demonstrated also include contingency management, in the event of unobtainable or conflicting goals, and coordination with tactical and strategic intelligent system specialists. These specialists are intelligent maneuvering (outer-loop) systems capable of incorporating planning and decision-making models to give the vehicle goal directed self-reliant behavior, enable time-critical re-planning and execution adaptation to compensate for unexpected internal and external conditions, or various mission-specific science related findings.[23]

Technical challenges will stem from real-time sensing, computing and communication requirements, environmental and operational uncertainty, hostile threats and the emerging need for improved UAS and UAS team autonomy and reliability. Significant challenges will also relate to inter-UAS communications, links to command and control, contingency management, Challenges increase significantly as one move up the hierarchy of the chart from single to multi-vehicle coordinated control. Only moderate success has been currently reported in meeting the lower echelon challenges, leaving open the whole field for subsequent developments. Technically, to meet stated challenges, innovative coordinated planning and control technologies such as distributed artificial intelligence (DAI), multi agent System (MAS) theory, computational intelligence and soft computing, generalized system theory, as well as game theory and dynamic optimization, coupled with sophisticated hardware and software architectures will be needed. Even though related approaches and methodologies have been investigated intensively in recent years, such as formation control and autonomous search, while less attention has been paid to the overall 'system architecture' concept, especially from an implementation and integration [4][7][10][12][13][15][19][23][27][28][29][30][33].

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IX. CHALLENGES, ENABLING TECHNOLOGIES

All of the above notwithstanding, there is consensus on a number of challenges that need be met before UAS fly routinely in civilian airspace. Even though smaller UAS will fly first the following are true: Safety, safety, and more safety, with all prerequisites and aftermath attached to it. The public will not tolerate accidents; it is as simple as that.

- **Sense and Avoid technology**: The NTSB members expressed particular interest in the ability of UAS to handle contingencies beyond close encounters in shared airspace [3]. A pilots ability to "see-and-avoid" other aircraft in shared airspace is an important part of civil aviation. It appears logical to require a similar capability of unmanned flight.[7] The intent of "see and avoid" is for pilots to use their sensors (eyes) and other tools to find and maintain situational awareness of other traffic and to yield the right-of- way, in accordance with the rules, when there is a traffic conflict.[30]
- **Bandwidth regulation.**
- **Lost Link Procedures:** In all cases, the UAS must be provided with a means of automatic recovery in the event of a lost link. There are many acceptable approaches to satisfy the requirement. The intent is to ensure airborne operations are predictable in the event of lost link.[3]
- **Flight Termination System (FTS**): It is highly desirable that all UAS have system redundancies and independent functionality to ensure the overall safety and predictability of the system. If a UAS is found to be lacking in system redundancies, an independent flight termination system that can be activated manually by the UAS pilot in command may be required to safeguard the public.
- **Autonomous Operations:** At first only those UAS that have the capability of pilot intervention, or pilot-in-the-loop, shall be allowed in the NAS outside of Restricted, Prohibited, or Warning areas. UAS that are designed to be completely autonomous, with no capability of pilot intervention, are going to be the last to be authorized for operations in the national airspace system.
- **Onboard Intelligence challenges :** Onboard intelligence, Teaming/swarming[35], Health Management (ACL 2), Collision Avoidance, Affordability, Sensing.

Data links challenges:

Designing aeronautical wireless data links is much more challenging than other wireless links. The key challenges are: Long Distance, High-Speed, and Spectrum. In this section we review these challenges. [26]

New data links need to be developed for Unmanned Aircraft Systems (UAS) and for commercial manned particularly because they will share the same non-segregated air space and would need to be aware of each other's presence. The key challenges in the design of aeronautical communication systems are the large distances that they need to cover and the high-speed of aircrafts. These along with the limited availability of radio frequency spectrum affect the performance of the data link.[26]

UAS data link design needs to meet are: [26]

- High-availability: We need new metrics to allow risk assessment for sense and avoid applications.
- Networked and Non-networked controllers: Both cases need to be covered.
- Preemption: Need a multi-priority design to allow urgent communications to continue.
- Chaining: To allow UASs to communicate to ground stations via other UASs
- Compatibility with manned aircraft datalinks

The challenges facing all military and other forces Services
Interoperability: To achieve the full potential of unmanned systems, these systems must operate seamlessly across the domains of air, ground, and maritime and also operate seamlessly with manned systems. Robust implementation of interoperability tenets will contribute to this goal while also offering the potential for significant life-cycle cost savings.

Autonomy: Today's iteration of unmanned systems involves a high degree of human interaction. DoD must continue to pursue technologies and policies that introduce a higher degree of autonomy to reduce the manpower burden and reliance on full-time high-speed communications links while also reducing decision loop cycle time. The introduction of increased unmanned system autonomy must be mindful of affordability, operational utilities, technological developments, policy, public opinion, and their associated constraints.

Airspace Integration (AI): DoD must continue to work with the Federal Aviation Administration (FAA) to ensure unmanned aircraft systems (UAS) have routine access to the appropriate airspace needed within the National Airspace System (NAS) to meet training and operations requirements. Similar efforts must be leveraged for usage of international airspace.

Communications: Unmanned systems rely on communications for command and control (C2) and dissemination of information. DoD must continue to address frequency and bandwidth availability, link security, link ranges, and network infrastructure to ensure availability for operational/mission support of unmanned systems. Planning and budgeting for UAS Operations must take into account realistic assessments of projected SATCOM bandwidth, and the community must move toward onboard pre-processing to pass only critical information.

Training: An overall DoD strategy is needed to ensure continuation and Joint training requirements are in place against which training capabilities can be assessed. Such a strategy will improve basing decisions, training standardization, and has the potential to promote common courses resulting in improved training effectiveness and efficiency.

Propulsion and Power: The rapid development and deployment of unmanned systems has resulted in a corresponding increased demand for more efficient and logistically supportable sources for propulsion and power. In addition to improving system effectiveness, these improvements have the potential to significantly reduce life-cycle costs.

Manned-Unmanned (MUM) Teaming: Today's force includes a diverse mix of manned and unmanned systems. To achieve the full potential of unmanned systems, DoD must continue to implement technologies and evolve tactics, techniques and procedures (TTP) that improve the teaming of unmanned systems with the manned force.

This Roadmap leverages individual Service roadmaps and visions, and identifies challenges that might stand in the way of maturing those visions to a shared Joint vision. The vignettes provided at the beginning of the Roadmap give the reader a glimpse into potential unmanned systems capabilities. They do not serve as requirements—the individual Services will continue to identify requirements gaps and utilize the Joint Capabilities Integration and Development System (JCIDS) to determine which requirements to fund. The chapters that follow the vignettes identify core areas that are challenges for further growth in unmanned systems and chart out science, technology, and policy paths that will enable unmanned systems to fulfill an expanding role in supporting the warfighter. Success in each of these areas is critical to achieve DoD's shared vision and realize the full potential of unmanned systems at an affordable cost.[27]

X. CONCLUSION

In this survey paper, we try to review Unmanned Aircraft Systems (UAS) which is an emerging technology with a tremendous potential to revolutionize warfare and to enable new civilian applications. UAS today play an increasing role in many public missions such as border surveillance, wildlife surveys, military training, weather monitoring, and local law enforcement. As a result, the Unmanned Aircraft Systems (UAS) required more exploration. During the review, we also find some points that can be further explored in the future. We will try to explore deeper in this area.

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