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Terrain imperatives for Mini unmanned aircraft systems applications

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Abstract

Purpose – Amongst all classes of unmanned aircraft system (UAS), the rise of the Mini UAS class is the most dominant. Mini UASs are field-deployable systems and hence are not expected to operate from a runway. Therefore, the operating terrain plays an important role in the deployment and employment of the Mini UAS. However, there is limited published work in this area. The impact of terrain is more critical for military applications than civilian applications. The purpose of this paper is to explore the implications of various types of terrain on the employment and deployment of Mini UAS.

Design/methodology/approach – This paper explores the implications of various types of terrain on the employment and deployment of Mini UAS.

Findings – Mini UAS with field deployable requirements is often launched within the tactical battle area in case of military applications or in close proximity to the intended target area for civilian applications. Due to the size and weight of the Mini UAS, launch and recovery becomes an important factor to be considered. Rotary wing or fixed-wing vertical take-off and landing configuration UAS overcomes the limitations of Mini UAS and hence it is the preferred option. Impact of the terrain is significantly higher for military applications as compared to civil applications. Mountain terrain is the most challenging for Mini UAS operations.

Practical implications – This paper will help the designers configure the UAS as per the operating terrain.

Originality/value – Terrain affects the deployment and employment of Mini UAS and the capabilities of the system with respect to terrain in which it is expected to operate must be considered during the design of a Mini UAS. The paper will help the designers configure the UAS as per the operating terrain.

Keywords Mini UAS, Mini UAV, Terrain implications for UAS, Classification of Mini UAS, Applications of Mini UAS

Paper type General review

1. Introduction

Unmanned aircraft system (UAS) can be defined as a "system whose components include the necessary equipment, network, and personnel to control an unmanned aircraft (US Department of Defense, 2013)." Miller (2016) provides a detailed account of the evolution of UAS from flying bombs to its present sophisticated form. UAS established itself as a potent force multiplier during Gulf War 1. Between the Gulf War 1 and 2, UAVs saw a significant growth. UAS was a key element in the US military's network-centric warfare-based Gulf War 2. Because of its proven capabilities, UAS is increasingly used for a multitude of military and civil applications. UAS, besides offering the advantages of no risk to human life and lower cost of operations, provide a broad range of mission capabilities. Consequently, from the erstwhile reconnaissance and surveillance only role, UAS is being used for varied military applications. UAS is being progressively used for various civilian applications, significantly expanding the market for the aerial systems. Research in the UAV domain has seen a sharp increase in the recent years. As per the study by Kotsemir (2019), Scopus publications on UAS-related topics saw an explosive rise from 539 in 2000 to 23,502 in 2015. Various studies suggest that Mini UAS is the fastest growing segment amongst all classes of UAS. As per the study by Teal group (Teal Group, 2014) , the UAS sector in the decade between 2015 and 2024 was expected to rise by 79%. In the same period, the study also predicts a rise in worldwide



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R&D budget for UAS from 2,870 to 30,251 million dollars. Amongst all classes of UAS, the rise of the Mini UAS class is the most dominant. Mini UAS are field deployable systems and hence are not expected to operate from a runway. Therefore, the operating terrain plays an important role in the deployment and employment of the Mini UAS. However, there is limited published work in this area. The impact of terrain is more critical for military applications than civilian applications. This paper explores the implication of various types of terrain on the employment and deployment of Mini UAS.

The rest of this paper is organized as follows: in Section 2, various methods of classification are studied and specific working parameters for Mini UAS are established after due analysis. Section 3 reviews the critical factors that dictate Mini UAS deployment and applications, in terms of range, endurance, operating altitude, maximum take-off weight (MTOW) and payload capabilities. Section 4 addresses terrain implications for the deployment and employment of Mini UAS. Compared to civilian applications, terrain significantly impacts military applications. The factors that dictate the employment and deployment in urban, desert, mountain, jungle and coastal terrain are different. In Section 5, we present the analysis and findings that will provide researchers, designers and manufacturers a clear understanding of the terrain factors that dictate the Mini UAS applications. Finally, in Section 6, a number of conclusions are drawn. For ease of understanding, all acronyms are summarized in Table 1 before proceeding to the next section.

2. Classification of UAS and categorisation of Mini UAS

UAS comprises several sub-systems which include the pilotless aircraft referred to as the unmanned aerial vehicle (UAV) (Austin, 2010; Sadraey, 2020). Various sub-systems of the UAS is depicted in Figure 1. US DoD dictionary defines UAV as "A powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload (US Department of Defense, 2013)." Essentially, the UAV is the airborne component of the UAS. The ground control station (GCS) acts as the interface between system operators and the rest of the system. For larger systems like the RQ-4 Global Hawk, the GCS is a shelter-based sophisticated set up which houses the system operators. For smaller UAVs, the GCS is a small portable entity.

A dedicated launch and recovery station (LRS) is usually applicable for higher classes of UAS. The LRS in such cases are similar to the GCS. Small UAVs have simple launch and recovery mechanism and are usually hand launched or catapulted launched. Data link facilitates the communication between GCS/LRS and the UAV, usually achieved through

Table 1.
List of acronyms

Acronyms			
AGL	Altitude above ground level	LoS	Line of sight
AMSL	Above mean sea level	LRS	Launch and recovery station
CAGR	Compound annual growth rate	MALE	Medium-altitude long endurance
DoD	Department of defence	MAV	Micro aerial vehicles
FLOT	Forward line of own troops	MTOW	Maximum take-off weight
GCS	Ground control station	TBS	Tactical battle space
GDT	Ground data terminal	UAS	Unmanned aircraft system
HALE	High-altitude long endurance	UAV	Unmanned aerial vehicle
ISTAR	Intelligence, surveillance, target acquisition and reconnaissance	VTOL	Vertical take-off and landing

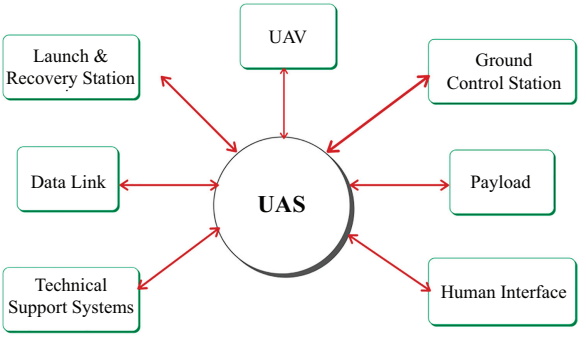


Figure 1.
Various components of the UAS

radio transmission. Payload output and UAV data are displayed on the GCS through the data link. Range of the UAS is related to the capability of the data link. Bigger UAS like MQ-1 Predator can carry multiple interchangeable payloads. In case of smaller UAS, the payload is limited by the intended application for which the UAS is expected to be used. The technical support systems include maintenance, power supply equipment, transport items and such like support equipment. Higher class of UAS requires complex and elaborate technical support systems. The human interface of the UAS includes both the operating crew and the technical crew. Apart from the complexity and class of the UAS, terrain also impacts each sub-system of the UAS. The same shall be discussed later in the article.

2.1 Classification of UAS

Endurance, range, weight, altitude, size, wing loading and engine type are the principal performance characteristics considered for classification of UAS by various authors (Dalamagkidis, 2015; Austin, 2010; Sadraey, 2020; Maziar *et al.*, 2013). Based on these parameters, these UAS are classified as high-altitude long endurance (HALE) UAS, medium-altitude long endurance (MALE) UAS, tactical UAV, small UAS and Mini and micro UAS (Austin, 2010; Sadraey, 2020; Dalamagkidis, 2015; Maziar *et al.*, 2013; Cai *et al.*, 2014; Anderson and Gaston, 2013; Gupta *et al.*, 2013; Weibel and Hansman, 2004; Hassanalian and Abdelkefi, 2017; Villa *et al.*, 2016). The HALE classes of UAS are capable of trans-global flights and have extremely long range. Endurance exceeds 24 h and can fly at attitudes in excess of 6,000 m above mean sea level (AMSL). MALE class has an endurance of about 24 h and flies at altitudes exceeding 4,500 m AMSL. MALE class has ranges in excess of 500 km, but when the data link is established trough satellites, range increases considerably. Both HALE and MALE class of UAS can be tasked identical roles. Tactical UAS can fly at altitudes beyond 3000m AMSL and range up to 300 km with 10–12 h endurance.

NATO classifies UAS into three classes based on weight. Class I UAS has less 150 kg, Class II 150–600 kg and Class III in excess of 600 kg (Dalamagkidis, 2015; Demir *et al.*, 2015). Class I aligns with small, mini and micro UAS. Tactical UAS forms part of Class II UAS, and Class III UAS includes HALE and MALE UAS. Details of few popular HALE, MALE and Tactical UAS are depicted in Table 2.

There is a certain amount of uniformity amongst the authors in classification of bigger UAVS like RQ-4 Global Hawk and MQ-1 Predator. Even for the micro or miniature UAVs like the Black Widow UAV, classification is more or less standard. However, there is an overlap when it comes to distinguishing between small, Mini or micro UAVs. Small UAV covers a wide spectrum and could be either a tactical UAV or a Mini UAV or even micro UAV. Figure 2 gives out a spectrum of the current UAV.

Class	UAS	Manufacturer
HALE UAS	RQ-4 Global Hawk	Northrop Grumman
	MQ-4 Triton	Northrop Grumman
	Guizhou Soar Dragon	Guizhou Aircraft Industry Corporation
	RQ-3 DarkStar	Lockheed Martin
	Phantom Eye	Boeing
	Cloud Shadow	Chengdu Aircraft Industry Group
MALE UAS	MQ-1 Predator	General Atomics
	Wing Loong	Chengdu Aircraft Industry Group
	IAI Heron	Israel Aerospace Industries
	Rustom-II	Aeronautical Development Establishment
	Firebird	Northrop Grumman
	Hermes 900	Elbit Systems
Tactical UAS	Searcher Mk II	Israel Aerospace Industries
	Bayraktar TB2	Baykar Makina
	Hermes 450	Elbit Systems
	Nishant	Aeronautical Development Establishment
	Rotary-Bat	Northrop Grumman
	Watchkeeper X	Thales Group

Table 2.
Details of HALE, MALE and Tactical UAS

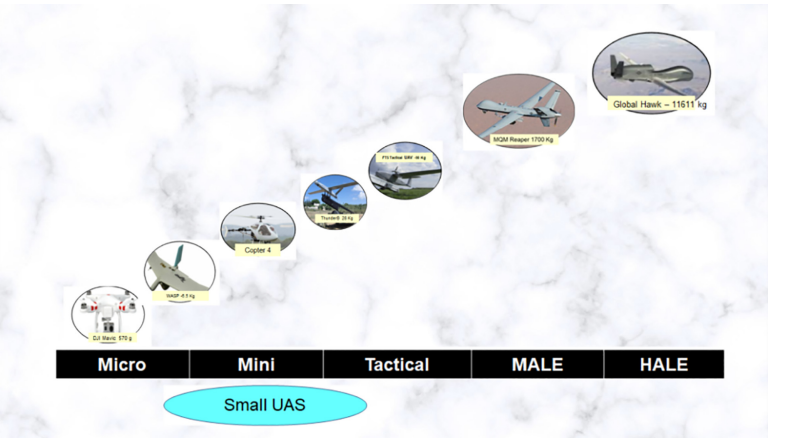


Figure 2.
UAS spectrum

2.2 Categorisation of Mini UAS

While there is uniformity amongst various authors and UAS manufacturers with respect to HALE, MALE and tactical UAS, the same is not the case with Mini UAVs.

The lines are blurred when it comes to differentiating between small, mini or micro UAS. The spectrum of small UAS ranges from micro to tactical UAS as shown in Figure 2. The ambiguity amongst manufacturers is depicted in Figure 3. The MTOW ranges from 5 to almost 100 kg and the altitude from below 500 m to 7,000 m plus AMSL.

The authors (Ramesh and Jeyan, 2020) carry out an elaborate analysis of the works of various researchers and data from UAS manufactures to define Mini UAS. The working parameters established for Mini UAV have range of 30–40 km, ceiling altitude approximately 3,500 m AMSL, endurance 3–4 h and MTOW less than 30 kg (see Figure 4).

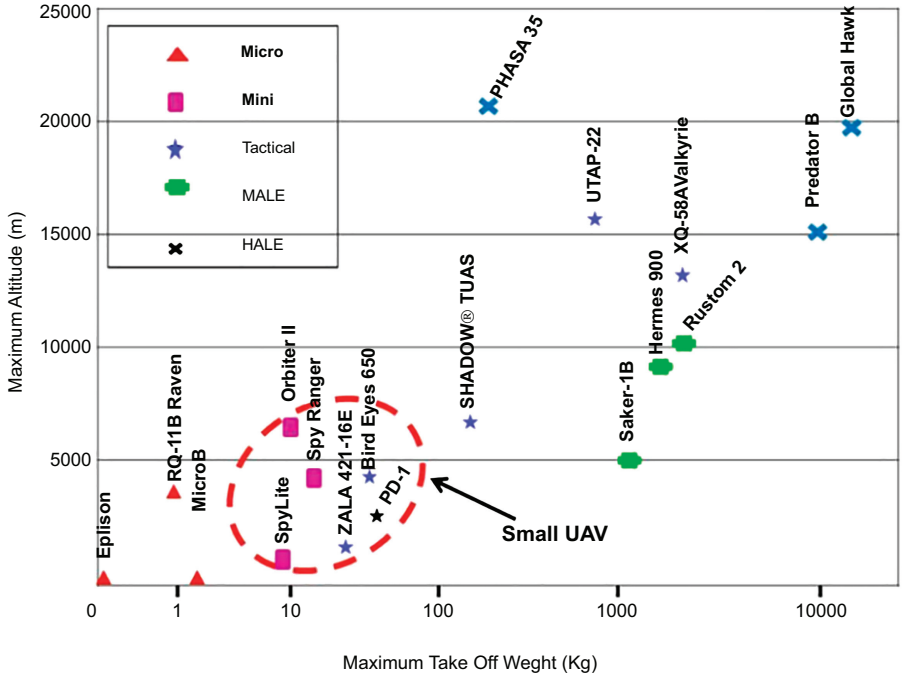


Figure 3.
Classification of UAS by manufacturers

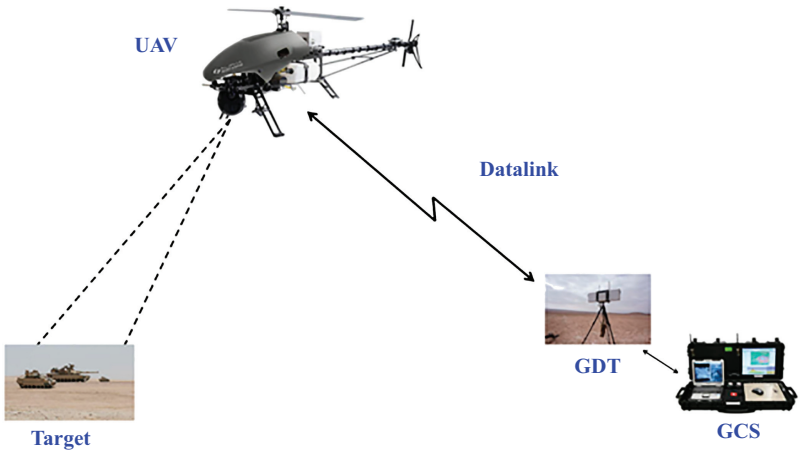


Figure 4.
Deployment of UAS

3. Mini UAS applications and deployment considerations

Deployment of UAS is related to its intended application. More often than not, Mini UAS will not be operated from a runway, particularly for military applications. A typical UAS deployment is depicted in Figure 2.

3.1 Application considerations

Crouch (2005) brings out that the locally controlled Mini UAS provides situational awareness to tactical commanders without relying on strategic and operational level UAS. These organic assets have the ability to collect data relevant to small unit commanders. Edwards (1990), emphasises on three elements for Mini UAS at tactical level – reconnaissance, surveillance and target acquisition. In the study by Naval Studies Board (2005), the need for continuous or persistent surveillance has been highlighted. Strike role for Mini UAS is not envisaged because of limited payload carrying capability and small airframe. In addition to intelligence, surveillance, target acquisition and reconnaissance (ISTAR) roles, as per Weed (2002), ability to relay communications is also envisaged for Mini UAS at brigade level operations. Mini UAS significantly supplements artillery spotting capabilities, and this capability is being exploited by Russian artillery (Grau and Bartles, 2016).

Because of pricing issues and regulatory restrictions associated with larger military UAS, these UAS are not an attractive proposition for commercial applications (Miller, 2018). On the other hand, due to low cost and accessibility of technologies, Mini UAS has penetrated into the civilian market in a big way. Survey by various agencies indicates a sharp rise in the small UAS segment with an expected growth in excess of 14% CAGR (Markets, 2019; Lukas Schroth, 2019; Mordor Intelligence, 2019). Mini UAS are being used for a variety of civilian applications. These include law enforcement, fire fighting, forest fires, emergency rescue, oil and gas industry distribution infrastructure monitoring, electricity grids/distribution networks monitoring, agriculture, forestry, fisheries, environmental monitoring, crop dusting, precision agriculture, Earth observation and remote sensing, climate monitoring, aerial photography, cinematography, mapping and surveying, seismic events, pollution monitoring, communications and broadcasting and such like applications (Teal Group, 2014; Austin, 2010; European Commission, 2007; Pricewaterhouse Coopers and Agoria, 2015; Aswini *et al.*, 2018).

3.2 Deployment factors

The capabilities of UAS in terms of range, endurance, operating altitude, MTOW and payload capabilities dictate the deployment of the UAS.

(1) *Range.* Operating range is the radial distance between the GCS and the UAV. Range is dependent on line of sight (LoS) data link and the endurance of the UAV. UAVs for civil applications can be launched close to the target location; therefore range is not a restricting factor. But in case of military application, the tactical employment will dictate the range requirement.

(2) *Endurance.* Endurance is the airborne time of the UAV. Endurance is dependent on performance of the power plant of the UAV and the operating terrain. For most military applications like surveillance, endurance a critical factor to avoid losing track of the target. Apart from this, the battlefield conditions dictate that the aircraft will have to be launched from a distance from the adversary's target location. The consequent dead mileage adds to the endurance requirement.

(3) *Altitude.* AMSL ceiling defines the operating altitude UAV. Altitude is a critical factor when the UAV has to be launched from higher AMSL altitudes. Stealth and the requirement to fly beyond the small arms range are important design considerations under battlefield conditions. For civil applications, factors that affect operating altitude include the launch altitude and the capability of the payload.

(4) *MTOW.* Mini UAS are man-portable field deployable systems and hence are not expected to operate from a runway. A higher weight has significant implications if the

UAS has to be physically transported cross-country. In such a scenario, apart from the aircraft, weight of all other sub-systems assumes critical significance. Unlike military applications, vehicular transportation of the UAS to a suitable location will be feasible for most cases for civilian applications, and hence MTOW will not be a restricting factor.

4. Terrain implications

Terrain impacts both the deployment and employment of UAS. Terrain, in a military context, corresponds to a geographical area of ground in relation to its use in a particular operation. The tactical battle space (TBS) for UAS operations is as shown in Figure 5. UAS employed for an operation must be able to cover the area of interest. Area of interest as per (Office of the Chairman of the Joint Chiefs of Staff, 2020), is "that area of concern to the commander, including the area of influence, areas adjacent thereto, and extending into enemy territory". Area of influence is "a geographical area wherein a commander is directly capable of influencing operations by manoeuvre or fire support systems normally under the commander's command or control" (Office of the Chairman of the Joint Chiefs of Staff, 2020). For a brigade, the area of interest extends beyond the forward line of own troops (FLOT) to a distance of approximately 30 km (Edwards, 1990; Blom, 2010). Extending the analogy, the area of interest for civilian applications is determined by the intended target area. The requirement of range for the UAS is therefore determined by the area of interest in case of military applications. However, unlike military operation affected by battlefield threat, the UAS for civilian application can be deployed close to the target area. The flexibility of deployment for Mini UAS for civilian applications overcomes many restrictions imposed by the terrain, the same has been explained later in the article. Therefore, the primary focus of the paper will be on terrain implications for military applications. Impact of various types of terrain on the deployment and employment of Mini UAS are discussed in succeeding paragraphs.

4.1 Urban terrain

Urban terrain is a combination of manmade construction and natural landscape. Urban areas can be classified by building height, separation and street width. It comprises a combination of the city core, commercial ribbon, core periphery, residential sprawl, outlying industrial areas and outlying high-rise areas. Presence of multidimensional battle space, i.e. building, street, subterranean and air, is a distinctive terrain feature (Marine Corps, 2001; Scott Gerwehr, 2000).

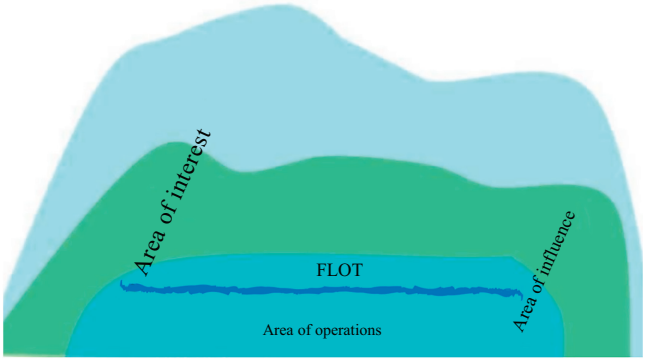


Figure 5.
TBS for UAS operations

Due to the constraints of terrain, small tactical units are usually the central players in urban conflict, with control sometimes devolving all the way down to squad level (Scott Gerwehr, 2000). As per Samad *et al.* (2007), the UAS in urban terrain function with one or two operators with a light UAV and ruggedized laptops as GCS. The endurance of UAV is limited to 60 min. Larger number of small units with UAVs with endurance limited to one hour implies that micro aerial vehicles (MAVs) as opposed to Mini UAS, is the preferred system for urban terrain. Another restricting factor in urban terrain is the obstruction of data link because of the presence of tall buildings. While the requirement to scan numerous by-lanes and buildings necessitates the use of MAVs, it would be incorrect to assume that Mini UAS has no role in urban terrain. Mini UAS offers the advantages of longer endurance for persistent surveillance, longer ranges and higher operating altitudes that provide higher survivability against small arms fire. Mini UAS can be transported on vehicles, hence heavier UAS can be used. In case of heavier fixed wing UAVs, catapulted launch is an option, but the recovery of the flying machine can be challenging due to limited availability of open spaces. Use of vertical take-off and landing (VTOL) UAV, rotary wing or fixed wing VTOL, can overcome this terrain imposed limitation.

4.2 Desert terrain

The complexity of deserts in terms of terrain, vegetation, climate and weather events significantly shapes the military operations. Military operations in desert terrain cover large distances because of large tracts of arid, dusty, rugged and barren landscape (Gilewitch *et al.*, 2014). The US Marine Corps document on deserts operations (Corps, 1993), provides a detailed account of the implications of desert terrain for military operations. Limited roads are available and most movements are cross-country. Trafficability is poor in soft sand, rocky areas and salt flats. The vastness of the desert makes mobility a prime concern. The few roads and desert tracks available become a key terrain for military operations. Although sandy deserts are predominantly flat, dunes rising over does 300 m exist.

Desert terrain permits UAS to operate at long ranges without LoS restrictions. Since the military operations in desert terrain cover large distances, long range of the UAS becomes a critical factor. As the Mini UAS is expected to operate at longer ranges, higher endurance is essential. Flying time to the intended target area will be relatively longer than other terrain, and hence there will be considerable dead to and fro mileage. Catapulted launched bigger sized fixed wing Mini UAS can be used because the availability of vast open terrain facilitates recovery. The technical support systems for the launch can be carried on a vehicle, wheeled or tracked. However, in case of rocky plateau deserts with solid or broken rock at or near the surface can be a restricting factor for conventional landing. Parachute or net recovery will be a better option for Mini UAS operating in such a terrain. Desert winds can achieve very high velocities affecting the stability of light-weight Mini UAS and even restricting the usage in extreme conditions.

The presence of dust and sand in deserts demand higher maintenance for the systems. Cover and concealment are generally scarce in the desert, and hence movement can be detected easily. Due to the sand and dust signatures left due to the loose surface material. Thus, the efficacy of the UAS is high in desert terrain. Thermal sights are very effective at nights in deserts difference between ambient temperature and military equipment temperature. In desert terrain both fixed wing and Mini VTOL UAS are suitable, the latter being the preferred option.

4.3 Mountain terrain

From a military perspective, mountain terrain can be divided into three categories based on altitude. Foothills ranges from 600 to 1800 m AMSL, mountains from 1800 to 3,000 m and

terrain above 3,000 m altitude are classified as high-altitude terrain (Grau, 2011). Mountain operations are generally carried out at three different operational terrain levels. Level I terrain is located at the bottom of valleys and along the main lines of communications. Level II terrain lies between valleys and shoulders of mountains. Limited secondary lines of communication in the form of narrow roads and trails that cross this ridge system may be available. Dominant terrain of summit regions comprises Level III, where mobility poses enormous challenge. Battles are fought at Level III to control the summits overlooking the lines of communications in Level I (US Department of the Army, 2000). Irrespective of the appearance, rugged terrain is a common feature of all types of mountains. In addition to the operational terrain levels, mobility and specific combat skill requirement are important elements that classify mountains. Because of restricted ground mobility, aerial imagery assumes critical importance (United States Army, 2016).

Mountainous terrain impedes mobility. Vehicle-based transportation of the Mini UAS is feasible at Level I terrain, and to a limited extent at Level II. Since vehicular movement is not possible beyond Level II terrain, the weight of the Mini UAS assumes greater significance in mountains. In order to obtain a clear LoS, the Ground Data Terminal (GDT) establishing the data link between the GCS and UAV has to be deployed on the ridge line on a dominating height at Level III. More often than not, the location for obtaining optimum range will not be easily accessible. The GCS, which is physically connected through cables to the GDT, as shown in Figure 2, has to be located in close proximity. The requirement for clear LoS between the GDT and the UAV further compounds the problem. Therefore, all elements of the Mini UAS will have to be carried physically on foot to the ridge line. While negotiating steep gradients in rugged terrain by soldiers on foot, the weight of each component of the UAS becomes critical. The GCS power supply has to match the UAV endurance of 3–4 h. Therefore, the GCS, usually based on a ruggedized laptop, might require an external source of power supply and that adds to the weight of the overall system. Due to the limited availability of plain areas in mountain terrain, conventional runway type launch and recovery of fixed wing UAV will not be the desired option in mountainous terrain. Catapult launch, as opposed to hand launch, will be the requirement for fixed wing Mini UAV having an MTOW in excess of 20 kg. Recovery in this case will be parachute or net-based system. But that adds to the overall weight of the system. It is preferable to have smaller sized UAV with good ergonomics for mountain terrain. Ease of carriage will be facilitated by easily dismantable and ease of assembling of the system under field conditions. All the complexities associated with mountainous terrain get compounded in high altitude terrain. Therefore in mountainous terrain light weight VTOL UAV with high endurance is the most preferred option, in some cases the only option.

4.4 Jungle terrain

It is often said that in jungle warfare, the soldier often fights two enemies: man and nature. Various aspects pertaining to jungle warfare have been extensively covered in Canadian and US Army documents (Canada, 1978; US Army, 1944). Jungle terrain is often attributed to the entire area dominate by jungles, although in many cases, jungles may cover only a portion of the terrain. Dense tropical growth including underbrush, trees, vines and giant ferns, characterise jungles. Such terrain is often found at elevations between the lower foothills or beaches and the high areas above the timberline. Jungles are generally sparsely populated with limited roads and tracks. Weather conditions significantly alter the topography of jungles. During monsoons jungles become very dense. Based on vegetation, jungles are classified into two types – primary and secondary. Primary jungles have minimal undergrowth and are dominated by large trees. In case of secondary jungles, the undergrowth is much thicker and there are fewer large trees. Mobility in secondary jungles is much more difficult, particularly during monsoons (Leiter, 2017).

The periphery of the jungle terrain offers space for deployment of UAS. Critical for the coverage of UAV is deployment of the GDT, and this can affect the operating range of the UAS. For a large jungle, a tactical military unit employed only for a portion of the large area. Therefore, the UAV employment for support of the tactical unit must cover the desired area. In some cases, the terrain may facilitate the deployment of GDT within the forested area, particularly the primary jungles. Jungle vegetation provides adequate scope for excellent cover and concealment. Air to ground observation is poor, but any activity which has broken or disturbed the canopy can be picked up (Canada, 1978). Due to the cover and concealment offered by the terrain, the UAV will have to do repeated scans to pick up any existing telltale signs of military value. This implies that the Mini UAS must have high endurance. Mini UAS is being increasingly used for various forestry applications because of low cost, reliability, flexibility and provision of high-resolution data within a shorter time period. Deployment of UAS being a critical factor for jungle terrain, VTOL UAS is preferable because of the inherent flexibility in deployment.

4.5 Coastal terrain

Mini UAS in military operations will have to cover the littoral zone of coastal terrain in proximity to water. The shoreline could be built up area, jungles, hills or beaches. Military operations in coastal terrain include naval battles, land battles in coastal plains and sieges of coastal fortresses (Guth, 2005). Mini UAS can also be employed for military operations over an island. Therefore, the desired attributes for the Mini UAS will depend on the type of land terrain over which it is expected to operate. The use of UAS for various coastal engineering applications like mapping, surveying and monitoring has seen a sharp rise in the recent years (Drummond *et al.*, 2015; Turner *et al.*, 2016). Maritime patrolling is another popular law enforcement application of UAS.

Depending on the type of application, the UAV could be ship launched or ground launched. Longer range is feasible because of low attitude and clear LoS. Due to presence of high velocity wind conditions, stability of the UAV is an important factor in coastal terrain. In case of shipped launched UAV, the MTOW is not a critical factor and UAS for most naval operations will be ship based. Even for land launched systems, the terrain affords catapulted/runway launch and parachute/net recovery. For applications like maritime patrolling, long endurance is a requirement. TEKEVER *AR*3 with a wing span of 3.2 m, 80 km range, 23 kg MTOW and 10 h endurance, apart from military applications, is also used for long endurance maritime patrol missions. In coastal terrain, launch and recovery is not a criticality because of terrain conditions, and there are no severe restrictions on the employment of fixed wing Mini UAS.

5. Findings and implications

Important findings and its implications for the employment and deployment of Mini UAS are discussed in the succeeding paragraphs.

(1) Not all small UAS can be defined as Mini UAS. They can be categorised into a distinct class with specific operating characteristics and that has significant implications for various Mini UAS applications.

(2) Unlike MAVs, field deployable Mini UAVs are not hand launched and unlike the higher class of UAVs, Mini UAVs are generally not runway launched. Therefore, the operating parameters of the Mini UAS are critical design considerations. Range, endurance, operating altitude, MTOW and payload capabilities dictates the employment and deployment of the UAS. Design limitations with respect to any of

the parameters can restrict the Mini UAS applications, more so for military applications.

(3) UAS operating factors are critical, particularly for military applications, and the same has significant implications for the design considerations of a Mini UAS. When the terrain limitations are superimposed, the criticality for the operating factors rises exponentially. The higher class of UAS like MALE and HALE have long ranges, long endurance and high operating altitudes. These systems have complex launch and recovery mechanisms and are launched from airfields. MAVs either have VTOL configuration or are hand launched and expected to cover a limited area. Mini UAS with field deployable requirements is often launched within the tactical battle area in case of military applications or in close proximity to the intended target area for civilian applications. Due to the size and weight of the Mini UAS, launch and recovery becomes an important factor to be considered. Rotary wing or fixed wing VTOL configuration UAS overcomes the limitations of Mini UAS and hence is the preferred option.

(4) For military applications, Mini UAS are expected to operate in the TBS. The requirement of range and endurance for the UAS is determined by the area of interest in case of military applications. Terrain plays a major role in the employment and deployment of Mini UAS in the TBS. For civilian applications, flexibility of deployment aids in overcoming restrictions imposed by the terrain to a large extent.

(5) Summary of criticality of various parameters based on the terrain is as per Table 3. Terrain affects the deployment and employment of Mini UAS and the capabilities of the system with respect to terrain in which it is expected to operate must be considered during the design of a Mini UAS. The interplay between the terrain and operating factors is impacted the most in mountainous terrain. Some terrains like mountain deserts, coastal jungles and island jungles will have mixed attributes. In such cases, the parameter with higher criticality should be considered as a limiting factor. For most terrain, VTOL configuration, due to the inherent flexibility in deployment, is the preferable option.

6. Conclusion

We have presented a fairly comprehensive overview of the implications of various types of terrain for Mini UAS applications. Classification of UAS to arrive at a clear understanding of the definition of Mini UAS has been discussed. The application considerations and the influence of the deployment factors for applications have been presented. The implications of Mini UAS in urban, desert, mountain, jungle, coastal and mixed terrain have been analysed. Finally, we have completed this article with concrete findings and implications for the employment and deployment of Mini UAS. During the research, we also find the Mini UAS

	Criticality of parameter					
Terrain	Endurance	Range	Operating altitude	MTOW	Size	Launch and recovery
Urban	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Desert	High	Moderate	Moderate	Moderate	Moderate	Moderate
Mountain	High	High	Very high	Very high	High	Very high
Jungle	High	High	Moderate	Moderate	High	High
Coastal	Very high	Moderate	Moderate	Moderate	Moderate	Moderate

Table 3. Summary of terrain implications

design for military applications in mountain terrain is the most complex, and this aspect can be further explored in the future.

References

Anderson, K. and Gaston, K.J. (2013), "Lightweight unmanned aerial vehicles will revolutionize spatial ecology", *Frontiers in Ecology and the Environment*, Vol. 11 No. 3, pp. 138-146, doi: 10.1890/120150.

Aswini, N., Krishna, E.K. and Uma, S.V. (2018), "UAV and obstacle sensing techniques – a perspective", *International Journal of Intelligent Unmanned Systems*, Vol. 1 No. 3, pp. 256-275, doi: 10.1108/IJIUS-01-2013-0001.

Austin, R. (2010), *Unamnned Aircraft Systems: UAV Design, Development and Deployment*, Wiley. doi: 10.1016/B978-0-12-374518-7.00016-X.

Blom, J.D. (2010), *Unmanned Aerial Systems: A Historical Perspective*, Combat Studies Institute Press US Army Combined Arms Center, Occasional Paper 37.

Cai, G., Dias, J. and Seneviratne, L. (2014), "A survey of small-scale unmanned aerial vehicles: recent advances and future development trends", *Unmanned Systems*, Vol. 2 No. 2, pp. 175-199, doi: 10.1142/S2301385014300017.

Canada, D. (1978), "Jungle operations", *B-OG-302-004/FP-001*, 4(Cfp 30214), pp. 36-34.

Corps, U.S.M. (1993), "Desert operations", *Field Manual FM 90-3/FMFM*, pp. 7-27.

Crouch, C.C. (2005), *Integration of Mini-UAVs at the Tactical Operations Level Implications of Operations, Implementation, and Information Sharing*, Naval Postgraduate School, p. 199.

Dalamagkidis, K. (2015), "Classification of UAVs", *Handbook of Unmanned Aerial Vehicles*, Springer Reference, pp. 1063-1070, doi: 10.1007/978-90-481-9707-1_47.

Demir, K.A., Cicibas, H. and Arica, N. (2015), "Unmanned aerial vehicle domain: areas of research", *Defence Science Journal*, Vol. 65 No. 4, pp. 319-329, doi: 10.14429/dsj.65.8631.

Drummond, C.D., Turner, I.L. and Harley, M.D. (2015) "UAV applications to coastal engineering", *Australian Coasts and Ports 2015 Conference*, October, pp. 267-272.

Edwards, L.O. (1990), "A role for unmanned aerial vehicles on the modern tactical battlefield", *School of Advanced Military Studies United States Army Command and General Staff College Fort Leavenworth*, Kansas, p. 44.

European Commission (2007) "Study analysing the current activities in the field of UAV", *Entr/2007/065*, pp. 1-96.

Gilewitch, D.A. *et al.* (2014), "Characterizing the desert environment for Army operations", *GSA Reviews in Engineering Geology*, Vol. 22 August, pp. 57-68, doi: 10.1130/2014.4122(07.

Grau, L. (2011), "Mountain reconnaissance Russian style", *Mountain Warfare and Other Lofty Problems: Foreign Perspectiveson High-Altitude Combat*, Foreign Military Studies Office, pp. 80-87.

Grau, L. and Bartles, C. (2016), "Integration of unmanned aerial systems within Russian artillery", *Fires Bulletin* No. August, pp. 31-38, available at: https://community.apan.org/wg/tradoc-g2/fmso/m/fmso-monographs/195395.

Gupta, S.G., Ghonge Mangesh, M. and Jawandhiya, P.M. (2013), "Overview of unmanned aircraft systems", *International Journal of Advanced Research in Computer Engineering and Technology (IJARCET)*, Vol. 2 No. 4, pp. 1-23, doi: 10.2514/5.9781600868443.0001.0023.

Guth, P.L. (2005), "Coastal warfare", *Encyclopedia of Earth Sciences Series*, pp. 604-608, doi: 10.1007/1-4020-3880-1_59.

Hassanalian, M. and Abdelkefi, A. (2017), "Classifications, applications, and design challenges of drones: a review", *Progress in Aerospace Sciences*, Elsevier, Vol. 91 May, pp. 99-131, doi: 10.1016/j.paerosci.2017.04.003.

Kotsemir, M. (2019), *Unmanned Aerial Vehicles Research in Scopus: An Analysis and Visualization of Publication Activity and Research Collaboration at the Country Level, Quality and Quantity*, Springer. doi: 10.1007/s11135-019-00863-z.

Leiter, J.C. (2017), *The Soldier Must Be Trained Not to Fight the Jungle: Preparing the US Army for Future Operations in a Jungle Environment*, p. 74.

Lukas, S. (2019), "The drone market 2019-2024: 5 things you need to know", *DRONEII*, U.S. Army Command and General Staff College, Fort Leavenworth, Kansas, available at: https://www.droneii.com/the-drone-market-2019-2024-5-things-you-need-to-know.

Marine Corps, U. S. (2001), *Urban Attacks Military Operations on Urbanized Terrain (MOUT)*, Terrain, Vol. 1, Force Manual No 7-27.

Markets, M. (2019), "Unmanned aerial vehicle market, UAV size, share, system and industry analysis and market forecast to 2024", *Market Research Report*, available at: https://www.marketsandmarkets.com/Market-Reports/small-uav-market-141134567.html.

Maziar, A., Agostino, S., Mammone, M. and Nelson, M.Z.T. (2013), *Classification of Umanned Aerial Vehicles*, The University of Adelaide, Vol. 1, doi: 10.1051/e3sconf/20130111003.

Miller, J. (2016), "Strategic significance of drone operations for warfare", *E-International Relations*, pp. 1-15.

Miller, C.R. (2018), *Military Unmanned Aerial Vehicles and Diversification Opportunities*, University of Southern Mississippi, October, doi: 10.13140/RG.2.2.25777.02402.

Mordor Intelligence (2019), "Drones market- growth, trends, and forecasts (2020–2025)", available at: https://www.mordorintelligence.com/industry-reports/drones-market.

Naval Studies Board (2005), *Autonomous Vehicles in Support of Naval Operations*, The National Academies Press.

Office of the Chairman of the Joint Chiefs of Staff (2020), "DOD dictionary of military and associated terms", *Joint Education and Doctrine Division*, Vols J-7 January, p. 382, available at: https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/dictionary.pdf.

PricewaterhouseCoopers and Agoria (2015), "Drone's eye view", *Planning*, Vol. 81 No. 9, pp. 30-33.

Ramesh, P.S. and Jeyan, J.V.M.L. (2020), "Mini unmanned aerial systems (UAV) - a review of the parameters for classification of a Mini UAV", *International Journal of Aviation , Aeronautics , and Aerospace*, Vol. 7 No. 3, pp. 14-19.

Sadraey, M.H. (2020), *Design of Unmanned Aerial Systems, Design of Unmanned Aerial Systems*, Wiley, doi: 10.1002/9781119508618.

Samad, T., Bay, J.S. and Godbole, D. (2007), "Network-centric systems for military operations in urban terrain", *The Role of UAVs*, Vol. 95 No. 1, pp. 93-105.

Scott Gerwehr, R.W.G. (2000), "The art of darkness: deception and urban operations", *RAND Corporation*, p. 81, available at: https://www.rand.org/content/dam/rand/pubs/monograph_reports/MR1132/MR1132.chap2.pdf (accessed 6 August 2020).

Teal Group (2014), "Executive overview: the market outlook", *World Unmanned Aerial Vehicle Systems*.

Turner, I.L., Harley, M.D. and Drummond, C.D. (2016), "UAVs for coastal surveying", *Coastal Engineering*, Elsevier B.V., Vol. 114, pp. 19-24, doi: 10.1016/j.coastaleng.2016.03.011.

United States Army (2016), "Mountain Warfare and cold operations", *ATP 3-90.97*, April, pp. 36-41.

US Army, W. D. (1944), "Jungle warfare", *Field Manual FM 72-20*, p. 140.

US Department of Defense (2013), *Unmanned Systems Integrated Roadmap*.

US Department of the Army (2000), "Mountain operations", *Field Manual FM 3-97.6 (90-6)*, Vol. 6 No. November, pp. 1-11.

Villa, T.F., Gonzalez, F., Miljievic, B., Ristovski, Z.D. and Morawska, L. (2016), "An overview of small unmanned aerial vehicles for air quality measurements: present applications and future prospectives", *Sensors (Switzerland)*, Vol. 16 No. 7, pp. 12-20, doi: 10.3390/s16071072.

Weed, S.C. (2002), "The quality of quantity: Mini-UAVS as an alternative UAV acquisition strategy at the army brigade level", *Strategy*, p. 67.

Weibel, R.E. and Hansman, R.J. (2004), "Safety considerations for operation of different classes of UAVs in the NWeibel", in Roland, E. and John Hansman, R. (Eds), 2004, *Safety Considerations for Operation of Different Classes of UAVs in the NAS*, Vol. 1 No. September, pp. 341-351, Collection of Technical Papers - AIAA 3rd "Unmanned-Unlim', Collection of Technical Papers - AIAA 3rd 'Unmanned-Unlimited' Technical Conference, Workshop, and Exhibit. doi: 10.2514/6.2004-6421.

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