Evaluation of design criteria for mini unmanned aircraft systems (UAS) applications

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Abstract

Purpose – This paper aims to evaluate the factors that dictate the design of a mini unmanned aircraft system (UAS).

Design/methodology/approach – This paper analyses various dimensions that dictate the design criteria for a mini UAS.

Findings – Compared to civil applications, design of mini UAS for military application is much more challenging owing to combat restrictions. Topics related to civil applications dominate research in the field of mini UAS, with over 60% of the papers accounting for civil applications. Limited published articles related to military applications are available. While 86% of the in-production mini UAS is primarily meant for military applications, only 9% of the research is devoted to military applications of mini UAS. Most mini UAS, although designed primarily for military applications, are also extensively used for various civil applications. Critical aspects that influence the employment of mini UAS in the tactical battlespace are area of interest, type of operation, type of operational tasks, terrain and network-centric operations. All these factors collectively impact the design of a mini UAS.

Practical implications – According to various studies, mini UAS is the fastest growing segment amongst all classes of UAS. This paper will provide vital inputs to the designers and manufacturers of mini UAS for both military and civil applications.

Social implications – Mini UAS are in the list of "must-have" for modern militaries across the world and is also growing exponentially in the civil domain. Therefore, it is important to understand the critical factors that dictate the design of mini UAS.

Originality/value – To the best of the authors' knowledge, such an analysis is not available in the open domain.

Keywords UAV, UAV design, Mini UAS, UAV application, UAV classification

Paper type General review

1. Introduction

The term "mini" was associated with unmanned aircraft systems (UAS) for the first time with Mastiff Mk1, the 1978 Israeli unmanned aerial vehicle (UAV). However, it was only during 2003 Operation Iraqi Freedom Mini UAS established itself as a potent force multiplier in military operations. Mini UAS were used in large numbers during the war with great success (Blom, 2010; Coffey and Montgomery, 2002; Dalamagkidis, 2015a). UAS proved to be a critical asset for the US military during the war and was extensively used for real-time intelligence gathering, surveillance, reconnaissance, targeting and battlefield damage assessment particularly in high-threat areas which propelled the rise of mini UAS. Although numerous mini UAS are in use, both in military and civil domains, adequate attention has not been paid to the design criteria for these unmanned systems, driven by the requirements of precise applications. The paper aims to address the specific design aspects that need to be considered for mini UAS.

The rest of this paper is organised as follows. Section 2 categorises mini UAS as a distinct class of UAS and discusses various subsystems of UAS. In Section 3, various research areas and applications of mini UAS are analysed. The levels and echelons of warfare are discussed next, to establish the level at which mini UAS is expected to be used. The relevance of mini UAS in tactical battle space (TBS) and its employment considerations and the impact on design of mini UAS are presented and analysed. Thereafter, in Section 4, a summary of implications is presented for arriving at the design criteria for a mini UAS. Finally, Section 5 concludes the paper.

Various parameters used for classification include size, weight, range, endurance, operating altitude, speed, wing loading and engine type (Austin, 2010; Sadraey, 2020; US Department of Defense, 2005). Based on these parameters, various authors, researchers and UAS manufacturers have classified as high altitude long endurance (HALE) UAS, medium altitude long endurance (MALE) UAS, tactical UAV, close range, small UAS and mini and Micro UAS. NATO UAV classification guide (Joint Air Power Competence Centre, 2010) is another popular methodology for classification. Apart from various authors and researchers (Dalamagkidis, 2015b; Demir *et al.*, 2015; Hurst, 2019), many manufacturers, primarily USA based, refer to the NATO classification. Owing to the diverse methods of classification, there is an ambiguity regarding the categorisation of mini UAS. Based on analysis of the works of various authors and data from manufacturers, Ramesh and Jeyan (2020a), established the parameters for mini UAS. Quantified working parameters attributed for mini UAV are endurance 3–4 h, range 30–40 km, operating altitude in the region of 3,500 m AMSL and maximum take-off weight

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(MTOW) less than 30 kg. Further discussions will be based on these parameters.

The UAS comprises several subsystems, as depicted in Figure 1. Each subsystem impacts both the design and application of mini UAS. The operating parameters of mini UAS affect civil and military applications differently (Austin, 2010; Ramesh and Jeyan, 2020b; Sadraey, 2020).

2. Research and application of mini unmanned aircraft systems

Research in the UAV domain has seen a surge in the recent years. The number of UAV publications in Scopus saw an explosive rise from 539 in 2000 to 23,502 in 2015 (Kotsemir, 2019), and the trend is continuing. Growth of the UAV market with a compound annual growth rate over 14% during the period from 2019 to 2025 has been forecasted by various market surveys (Markets and Markets, 2019; Mordor Intelligence, 2020). However, the outcome of these studies could be flawed because of the ambiguous parameters used for categorising mini UAS (Table 1).

Details of research pertaining to mini UAS over the past two decades are given in Table 2. Categorisation of mini UAS by various authors does not necessarily fulfil the established criteria, and it is purely based on the classification by the authors. Although the assorted papers do not cover all the papers, it does represent the prevalent trend.

Mini UAS for civil applications started in the field of agriculture. In due course of time, the scope expanded to diverse applications, a sample of which can be seen from Table 2. Important military applications include intelligence, surveillance, target acquisition and reconnaissance (ISTAR), battle damage assessment (BDA) and similar tactical tasks (Austin, 2010; Jha, 2016; Sadraey, 2020).

Details pertaining to various mini UAS, as claimed by the manufacturers, are given in Table 3. It is evident from Table 3, that most UAS fails to satisfy all the parameters for a mini UAS. Only 12% of the mini UAS meets all the requirements of range 30–40 km, operating altitude in the region of 3,500 m AMSL, endurance 3–4 h and MTOW less than 30 kg.

The lack of uniformity of the performance parameters amongst manufactures, as evident from Table 3, could be because of inadequacy of research in the field of military applications. As seen from Figure 2, while 86% of the in-production mini UAS is primarily meant for military application, only 10% of the research is devoted to military applications. Topics related to civil applications dominate mini UAS research, with 67% of the papers accounting for the same. This paradox underscores the importance of establishing the design criteria for mini UAS applications. The comparative analysis of civil and military applications (Ramesh and Jeyan, 2020b) concludes that mini UAS designed for military applications can meet most of the requirements for civil applications. Therefore, the discussion and analysis will focus more on design criteria for military applications of mini UAS.

3. Levels and echelons of warfare and its influence on unmanned aircraft systems design

In most militaries across the world, warfare is typically addressed at three levels: strategic, operational and tactical (Bateman, 2015; Joint Chiefs of Staff, 2017; Romaniuk, 2015). British land operations doctrine (Ministry of Defence, 2018) follows similar levels of warfare concept. Mini UAS is expected to operate at the tactical level of war, where individual battles and engagements are planned and fought.

Corresponding to the levels, there are command groupings called echelon. Echelon structures essentially are a set of standard sizes into which units can be grouped. The strength and composition of the echelons will vary as per the militaries of a particular nation. Land forces echelons are typically classified as field army, corps, divisions, brigade and subordinate echelons [Ministry of Defence, 2018; US Department of the Army, 2019a; USAF College of Aerospace Doctrine, R. and E. (CADRE), 2016]. Similar organisational structure exists for the air force, the navy and marine corps across militaries of various countries (Ministry of Defence, 2018). Figure 3 depicts the correlation between and the levels and echelons.

Further discussions in this paper will focus on ground forces, and the conclusions drawn can be extended to the other forces

Figure 1 Sub systems of UAS

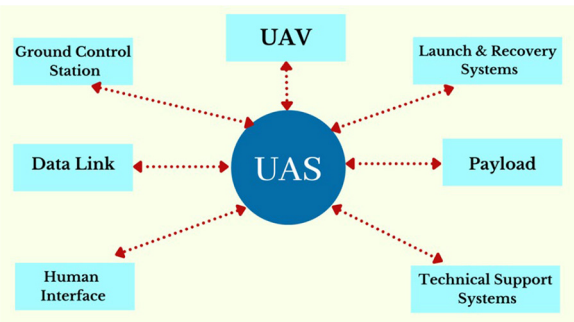


Table 1 List of acronyms

Acronyms		Acronyms	
AMSL	Above mean sea level	ISTAR	Intelligence, surveillance, target acquisition and reconnaissance
BDA	Battle damage assessment	MALE	Medium altitude long endurance
CAGR	Compound annual growth rate	MTOW	Maximum take-off weight
FLOT	Forward line of own troops	TBS	Tactical battle space
GCS	Ground control station	UAS	Unmanned aircraft system
GDT	Ground data terminal	UAV	Unmanned aerial vehicle
HALE	High altitude long endurance	UCAV	Unmanned combat air vehicles

Table 2 Research areas of mini UAS

Ref.	Title	Research areas
Coffey and Montgomery (2002)	The emergence of mini UAVs for military applications	Military
Anderson and Gaston (2013)	Lightweight unmanned aerial vehicles will revolutionize spatial ecology	Civil
Wang *et al.* (2013)	Application of mini-UAV in emergency rescue of major accidents of hazardous chemicals	Civil
Govorcin and Pribicevic (2014)	Comparison and analysis of software solutions for creation of a digital terrain model using unmanned aerial vehicles	Civil
Rawat and Lawrence (2014)	A mini-UAV VTOL platform for surveying applications	Civil
Lee *et al.* (2015)	Flexible membrane wing warping using tendon-sheath mechanism	Scientific
Giles and Billing (2015)	Deployment and performance of a UAV for crop spraying	Civil
Villa *et al.* (2016)	An overview of small unmanned aerial vehicles for air quality measurements: present applications and future prospectives	Civil
Kamali and Jain (2016)	Hardware in the loop simulation for a mini UAV	Scientific
Gross *et al.* (2016)	Flight-test evaluation of kinematic precise point positioning of small UAVs	Scientific
Ni *et al.* (2017)	Development of an unmanned aerial vehicle-borne crop-growth monitoring system	Civil
Hassanalian and Abdelke (2017)	Classifications, applications, and design challenges of drones: a review	Scientific
González-Jorge *et al.* (2017)	Unmanned aerial systems for civil applications: a review	Civil
Yarleque *et al.* (2017)	FMCW GPR radar mounted in a mini UAV for archaeological applications	Civil
Zhong *et al.* (2017)	Mini-UAV borne hyperspectral remote sensing: a review	Civil
Trizzino *et al.* (2017)	Applications of UAV photogrammetric surveys to natural hazard detection and cultural heritage documentation	Civil
Nations *et al.* (2018)	E-Agriculture in action: drones for agriculture	Civil
Ding *et al.* (2018)	Micro FMCW SAR with high resolution For mini UAV	Civil
Aswini *et al.* (2018)	UAV and obstacle sensing techniques – a perspective	Civil
Zhong *et al.* (2018)	Mini-UAV-borne hyperspectral remote sensing	Civil
Hartanto *et al.* (2019)	Intelligent unmanned aerial vehicle for agriculture and agroindustry	Civil
Shakhatreh *et al.* (2019)	Unmanned aerial vehicles (UAVs): a survey on civil applications and key research challenges	Civil
Xiang *et al.* (2019)	Mini-unmanned aerial vehicle-based remote sensing: techniques, applications, and prospects	Scientific
Hurst (2019)	Small unmanned aerial systems and tactical air control	Military
Radoglou-Grammatikis *et al.* (2020)	A compilation of UAV applications for precision agriculture	Civil
Shahmoradi *et al.* (2020)	A comprehensive review of applications of drone technology in the mining industry	Civil
Panigrahi and Tripathy (2020)	Design criteria of a UAV for ISTAR and remote sensing applications	Military
Escamilla *et al.* (2020)	Development and manufacturing of an albatross-inspired tilt-wing drone	Scientific
Özbek *et al.* (2020)	Evaluation of design methodology, limitations, and iterations of a hydrogen fuelled hybrid fuel cell mini UAV	Scientific
Rahman *et al.* (2021)	A comparative study on application of unmanned aerial vehicle systems in agriculture	Civil

with suitable modifications. The echelons and groupings will differ from country to country in terms of size, specialisation, equipment profile and capability, and the same has to be factored while considering the levels and echelons.

3.1 Tactical battle space

Tactical level of war lies at the lowest end of the spectrum. The division assigns areas of operations and missions to its subordinate echelons comprising brigade combat teams, multifunctional brigades or functional brigades. The size, composition and capabilities of the forces task-organized under a division headquarters will depend upon the type of operations undertaken (Ministry of Defence, 2018; US Department of the Army, 2019a). The type of operation undertaken will dictate the employment of UAS, details of which will be discussed subsequently in the paper.

3.2 Key factors in tactical battle space

3.2.1 Area of influence

Area of influence is a geographical area within which a commander can influence the operations by using the integral forces under his command and control (Office of the Chairman of the Joint Chiefs of Staff, 2020). Terrain and the capability of fire support at the disposal of the commander impact the extent of the area of influence.

3.2.2 Area of interest

Area of interest includes the area of influence and the areas adjacent thereto. Terrain, type and the scale of the operations dictate the area of interest (Office of the Chairman of the Joint Chiefs of Staff, 2020). It is critical for the commander to keep the area of interest under surveillance.

3.2.3 Area of operations

It is a geographical area defined by the commander with the aim to accomplish prescribed missions and protect forces under his command. The area of responsibility ascribed to an echelon is roughly equal to the area of operation (Edwards, 1990; US Department of the Army, 2019b).

3.2.4 Forward line of own troops

Forward line of own troops (FLOT) is an imaginary line indicating the forward most position of own troops. The line

Table 3 Details of mini UAS

Name	Manufacturer	Wing span (m)	Range (km)	Altitude (m) AMSL	Endurance	MTOW (Kg)	Primary application
RQ-11B Raven	AeroVironment	1.4	10	4,419	90 min	1.9	Military
Puma LE	AeroVironment	4.6	20	3,200	2 h 30 min	11.8	Military
Rotla Mini UAV	Rolta	2.8	20	3,500	4 h	10	Military
FQM-151A Pointer	AeroVironment	2.7	5	300	60 min	4.3	Military
Wasp	AeroVironment	1	5	3,499	50 min	1.3	Military
Spy'Ranger	Thales Group	3.9	30	4,500	2 h 30 min	14	Military
Bird-Eye 650 D	Israel Aerospace Industries	4.0	150	4,572	15 h	30	Military
BirdEye 650	Israel Aerospace Industries	3	20	457	4 h	11	Military
Mini Panther	Israel Aerospace Industries	3.2	20	500	2 h	12	Military
ZALA 421-16E	ZALA Aero company	1.6	50	3,600	7 h	18	Military
Bayraktar	Kale-Baykar	2.0	15	1,000	80 min	3.5	Military
Fly Eye	WB Group	3.6	30	4,000	2 h 30 min	11	Military
Guardian	OM UAV Systems	1.98	7.1	3,000	70 min	2.4	Civil
TEKEVER AR3	Tekever Autonomous Systems	3.2	120	NA	10 h	23	Military
PD-1	Ukrspec Systems	4	100	3,000	10 h	40	Military
LELEKA-100	Ukrspec Systems	1.9	45	1,500	2 h 30 min	5.5	Military
CYGNUS	Asteria Aerospace	2	15	5,000	90 min	4	Civil
Orbiter II	Aeronautics Defense Systems	3	50	5,486	3 h	10.3	Military
SpyLite	BlueBird Aero Systems	2.7	50	1,000	4 h	9.5	Military
CSV 15	TASUMA	2.7	20	NA	2 h	7	Military
Scan Eagle	Boeing	3.1	NA	5,000	22 h	18	Military
RQ-15A	DRS Technologies	2.1	75	2,438	4 h	36	Military
Stream C	Threod	3.9	50	3,000	6 h	6	Military
BOREY 20	UAVOS	4.3	430	3,500	5 h	20	Military
Albatross	Applied Aeronautics	3	40	NA	4 h	10	Civil
GLOBIHA	Global-Teknik	1.5	15	458	90 min	3.1	Military
Yamaha RMAX Type II	Yamaha Motor Company	3.1	NA	2,800	60 min	94	Civil
GSV-37 Breeze	Asturum Avia	2.2	0.15	1,000	90 min	12	Military
HoverEye	Bertin Technologies'	2.1	35	3,000	60 min	18	Military
Copter 4	Survey Copter	2.2	10	2,500	2 h 30 min	30	Military
FT-100 FH	FT Sistemas	2.5	40	1,524	2 h 30 min	NA	Military
SA-200 Weasel	Scion UAS	2.07	12	3,050	2 h 30 min	54	Military
HEF 30	High Eye.	1.8	NA	3,000	3 h 30 min	21	Military
Skeldar v-200	UMS Aero Group	4.6	15–50	NA	5 h	235	Military
SDO 50V2	Swiss Drones	2.8	90	3,000	NA	86	Military
KOAX X-240	Swiss UAV	2.4	NA	NA	90 min	45	Military
RH2 STERN	Delft Dynamics	1.8	NA	1,000	90 min	15	Military
Cypher	Sikorsky Aircraft	1.22	18	2,438	2 h	120	Military
FT-200 FH	FT Sistemas	2.8	NA	3,658	12 h	80	Military
VAPOR 55	AeroVironment	2.29	8	3,657	60 min	24.9	Military
INDELA-I.N.SKY GCS	KB INDELA Ltd	3.1	100	1,500 m	5 h	140	Military
UVH 25EL	UAVOS	2.6	67	3,500	90 min	25	Civil
CAMCOPTER S-100	Schiebel	3.4	200	5,486	10 h	200	Military
UVH 170	UAVOS	2.6	350	2,500	5 h	45	Civil
Panther VTOL	Israel Aerospace Industries	8.0	75	3,048	6 h	63.5	Military
PD-1 FW	Ukrspec Systems	4.7	100	2,500	12 h	45	Civil
EOS C UAS	Therod Sys	4.6	50	2,000	2 h	13	Military
ZALA 421-16EV.	ZALA Aero	2.8	100	2,000	2 h	10.5	Military
WanderB E M	Blue Bird Aero System	3.1	50	6,705	2 h 30 min	13	Military

extends to flanks of the forward most position (Office of the Chairman of the Joint Chiefs of Staff, 2020).

The areas in the TBS are as shown in Figure 4. Area of interest encompasses the area on influence, which in turn covers the area of operations. The FLOT lies within the area of operations and is not a stationary line. The line would shift as per the progress of the operations. These areas and FLOT provide the commanders an operational framework to visualise the battle space for application of combat power in time and space.

Figure 2 Research areas and application of mini UAS

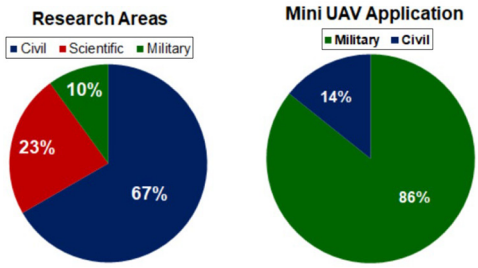


Figure 3 Echelons and levels

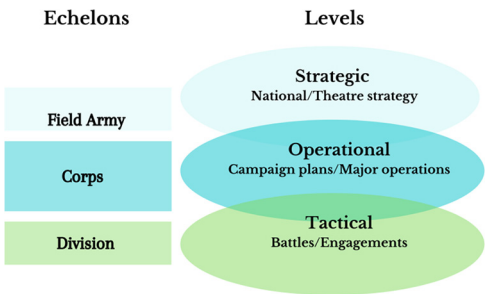
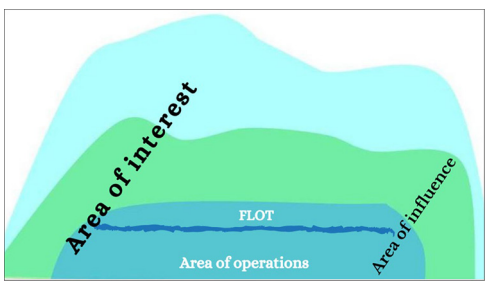


Figure 4 Areas in TBS



3.3 Relevance of mini unmanned aircraft systems in tactical battle space

For a division commander, area of interest extends to approximately 90 km beyond the FLOT (Edwards, 1990; US Department of the Army, 2019a). Tactical UAS having a range of 300 km will have to be used for surveillance over the area of interest, as the mini UAS has a range limited to around 30–40 km. The next echelon at the tactical level is the brigade. In case of a brigade, the area of interest extends beyond the FLOT to a distance of approximately 30 km, and for a battalion the area extends to about 15 km (Blom, 2010; Edwards, 1990; US Department of the Army, 2019a). Therefore, the highest echelon at which a mini UAS can be used is the brigade.

3.4 Tasks for mini unmanned aircraft systems in tactical battle space

Mini UAS can be used on the FLOT, on the flanks or in the rear areas of the brigade area of operations (US Department of the Army, 2006, 2017). Important tasks for which mini UAS are ised in TBS are discussed below.

3.4.1 Intelligence, surveillance, target acquisition and reconnaissance

At brigade level, the primary role for mini UAS involves ISTAR missions. Mini UAS through reconnaissance missions can provide near-real-time combat information. UAV, with its larger observation footprint, greater speed and an array of sensors, can cover a large area space within a short span of time, providing reliable results. Mini UAS are often used for detection, acquisition and designation of enemy targets. UAVs can fly into the enemy territory with stealth and pick up the positions for targeting. Once the target is acquired, the targets can be engaged by artillery guns (Blom, 2010; UK Ministry of Defence, 2011; United Nations Office for Disarmament Affairs, 2015; US Department of the Army, 2006, 2017).

3.4.2 Battle damage assessment

BDA is an important task for which mini UAS often used. Once the target is struck, UAVs can be used to assess the extent of damage caused. Based on the inputs received, the target can be re-engaged, if necessary (Blom, 2010; UK Ministry of Defence, 2011; US Department of the Army, 2006, 2017).

3.4.3 Other tasks

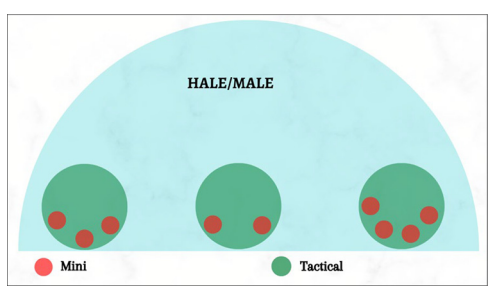
Other tasks for mini UAS include electronic intelligence, jamming, special purpose UAV, target and decoy, communication relay and logistics and similar applications (Austin, 2010; UK Ministry of Defence, 2011; US Department of the Army, 2006, 2017).

3.5 Synchronised employment of mini unmanned aircraft systems

The higher echelons having a larger operational spectrum cannot meet specific time critical tactical information requirements at brigade/battalion level. The availability of dedicated mini UAS at brigade/battalion level will enable these units to gather intelligence specific to the area of operation as per their requirement, in the desired time frame. However, mini UAS at tactical level will seldom operate in "stand-alone" mode. It will receive inputs from other UAS used by higher echelons, manned aircraft, ground-based systems and other sources. The higher echelon UAS will be a major supplier of information to the mini UAS operating in a network, which in turn will dictate the deployment and employment of mini UAS. Hence, UAS of multiple echelons becomes a "system of systems" as part of network centric operation (Joint Air Power Competence Centre, 2010; Kunertova, 2019; UK Ministry of Defence, 2011).

The area coverage of various UAS is as shown in Figure 5. HALE/MALE UAS used by the corps will look deep into

Figure 5 Coverage of UAS



enemy territory to keep the corps area of interest under surveillance. In case of defensive operations, enemy forces moving towards own area will be tracked and the divisions will have access to this information. When the enemy forces enter the area of a division, the integral tactical UAS will track the forces. Brigades will access to the information provided by the tactical UAS used by the division and/or the corps. As the enemy enters the brigade area of interest, mini UAS will track the enemy forces over a smaller area (Kunertova, 2019; US Department of the Army, 2017; US Marine Corps, 2015). Thus, the various echelons using UAS with varied capabilities will function as a networked system.

In offensive operations, the HALE/MALE UAS will be used in areas much beyond the enemy frontline defences. As the FLOT will shift forward with the movement of own forces, the tactical UAS of the division will be required to carry out reconnaissance of the enemy defences and the areas ahead of it. Mini UAS will be used by the brigades/battalions to support own offensive (US Department of the Army, 2006, 2018, 2019a). Synchronised usage of mini UAS in a network ensures optimum exploitation of the endurance because the mini UAS surveillance is based on prior inputs from other sources. The smaller UAS can exploit the information provided by the higher class of UAS, and hence the deployment range and endurance can be reduced.

3.6 Employment considerations and design criteria

Employment considerations of the mini UAS will determine the design criteria for the system. Critical aspects which influence the employment of mini UAS in the TBS are as under:

3.6.1 Area of interest

The distance between the forward edge of the area of interest and the FLOT will dictate the minimum range required by the UAS. It is also pertinent to note that the tactical and/or terrain considerations might compel the ground data terminal (GDT) to be located much behind the FLOT. This additional range requirement will have to be factored. Flying time to the farthest point will also affect the endurance. The extent of the area of interest will also dictate endurance required. Generally, in case of a brigade, it is in the region of 30 km × 30 km (Edwards, 1990; US Department of the Army, 2018, 2019b, 2019a). Therefore, the mini UAS design has to cater for a minimum range of 30 km.

3.6.2 Type of operations

In case of offensive operations, FLOT will shift forward with the progress of operations and the movement of own forces. Therefore, the area of interest will also correspondingly move ahead. This necessitates the UAV to fly farther to keep the area under surveillance. More often than not, the GDT will be placed at a vantage to obtain maximum possible range, and it may not be feasible to leapfrog the GDT while the UAV is airborne. In such a scenario, the distance between the GDT and UAV will increase. Hence, a longer range will have to be considered for offensive operations. For defensive operations, as the enemy forces close in, the requirement of range decreases. Mini UAS design should therefore be based on the requirements of offensive operations.

3.6.3 Type of task

ISTAR missions demand longer endurance. Tasks like BDA will require lesser endurance because the UAV is expected to fly over a known area that has already been targeted. Design endurance must be based on protracted operations to undertake the required tasks.

3.6.4 Terrain

Launch and recovery, location of GDT, operating altitude and its effect on MTOW impact the employment of UAS and in turn the design of the system. Terrain can therefore be a major limiting factor both in the deployment and employment (Ramesh and Jeyan, 2021). Operating altitude has multiple design implications. Firstly, the launch altitude and the altitude of the area where the UAV is expected to fly must be within the design parameters of the UAV. Secondly, the UAV must be capable to fly at above ground level beyond the range of small arms to ensure survivability. Thirdly, a UAV design with a smaller size is desirable in a high threat environment, but that will also have a corresponding effect on other performance parameters. Fourthly, at higher altitudes, the MTOW capacity of the UAV reduces and that will have a bearing on the endurance and payload carrying capacity.

3.6.5 Network centric operations

Mini UAS operating in a networked environment can leverage the longer ranges of the higher class of UAS. This would facilitate focused employment and hence would optimally exploit the range and endurance of the mini UAS. Therefore, it is important that the design of the mini UAS facilitates employment of mini UAS as part of the networked UAS.

4. Summary of findings and implications for design criteria

- Inconsistencies in specifying the performance parameters to categorise mini UAS, both by the research community and manufacturers, impact the design criteria for mini UAS. The specified performance parameters required for the intended applications drive design of the mini UAS. The parameters specified in this paper can serve as a benchmark for researchers, designers and manufacturers associated with mini UAS.
- As per the data from various manufacturers, only 12% of the mini UAS meets all the quantified parameters defined for mini UAS. This could be because of the inconsistencies in the performance parameters, driven by design criteria adopted, by various UAS manufacturers. This underscores the importance of designing the system based on common parameters.
- Mini UAS research is disproportionately biased towards civil applications, with very little focus on military applications. Paradoxically, close to 90% mini UAS are manufactured for military applications. Inadequacy of research in the field of military applications could have resulted in inconsistent design criteria adopted by the manufacturers.
- UAS comprises several subsystems. The capabilities of each subsystem affect the employment and deployment of the mini UAS. Therefore, the design criteria must be based both on the individual capabilities of each

subsystem and that of the mini UAS as a whole. This also implies that there will be variations in the design criteria based on the end use.

- Battlefield conditions and terrain impose several restrictions on the employment and deployment of the mini UAS. Therefore, the design of these systems for military applications is far more challenging than for civil usage. Mini UAS designed for military applications can meet most of the requirements for civil applications. Conversely, the systems purely designed for civil role may not meet tactical requirements.
- Employment of military UAS is based on the echelons of warfare in an integrated manner to facilitate seamless flow of information. Mini UAS design should cater for brigade level tactical requirements to operate in a networked environment. Key TBS factors that dictate the employment and deployment of the mini UAS and the level at which the system is used are important considerations for the design of a mini UAS.

5. Conclusion

A fairly comprehensive overview of the factors that dictate the design of mini UAS has been presented in this paper. Employment considerations and operating terrain will determine the design criteria for mini UAS. Therefore, the design of the mini UAS has to be based on these factors. As the primary element of the system is the UAV, aerodynamic configuration of the aircraft will have the maximum influence on the overall design criteria. Various aerodynamic configurations, i.e. fixed wing, rotary wing and hybrid configuration, of the mini UAV will have a bearing on the design of other subsystems as well. Further research is required to evaluate the optimum design configuration of the mini UAV and corresponding subsystems of Mini UAS.

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