Applications and Assessments of Uncrewed Aerial Vehicles for Dual-Use Public Good and Military Missions

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ABSTRACT

This paper discusses uncrewed aerial vehicles (UAVs) that can have additional applications beyond their respective civilian, industry, or military applications. The increasing popular electric UAVs in advanced air mobility (AAM) and urban air mobility (UAM) networks can be utilized to increase the efficiency and impact of emergency response in both urban and remote settings. The paper will explore the design considerations and requirements for these dual-use vehicles for specific public good missions, while presenting a survey of additional public good missions that could significantly benefit from additional ready-to-go drones. Additionally, this paper aims to explore the logistics required to implement a system for incorporating civilian, industrial, and military drones into a reserve fleet for emergency and disaster relief efforts.

NOMENCLATURE

AAM	Advanced Aerial Mobility
COTS	Commercial Off-The-Shelf
FAA	Federal Aviation Administration
FH	Flight Hour
GPS	Global Positioning System
LG	Landing Gear
MCP	Max. Continuous Power
MEQ	Mission Equipment
TRUAS	Tactical Resupply UAS
UAV	Uncrewed Aerial Vehicle
UAS	Uncrewed Aircraft System
UAM	Urban Air Mobility
ULS-A	Uncrewed Logistics System-Air

BACKGROUND

Historically, dual-use development has offered a frequent path to successful technology maturation and promulgation. The common examples of this paradigm often focus on electronics and their migration between consumer and soldier applications: the internet, telecommunications, GPS products, etc. (see Fig. 1, top left to right progression). Aviation as a broad field might justifiably argue itself as a dual-use arena of even greater success, even if it is less frequently discussed. When examining the evolution of platforms themselves from military to civilian missions, or the enabling components of these platforms like turbine engines, avionics, computers and “the internet” (see Fig. 1, bottom right to left progression), an observer notices a clear trend of co-dependency. In light of recent battlefield applications of quadcopter drones around the world, the two endpoints of the dual-use development paradigm could be viewed more as merging into a continuous cycle in which the origin of any given system as purely Civilian versus purely Military proves difficult to classify.

In this work, we seek to launch a discussion of dual-use missions for uncrewed aerial vehicles (UAVs) against the backdrop of two converging trends: (1) proliferation of electric vehicles across all areas of the aviation trade space, including the anticipated arrival of electric Advanced Air Mobility (AAM) and Urban Air Mobility (UAM) networks, and (2) a set of rapidly multiplying public needs for aviation that require a resilient aircraft ecosystem – especially in the field of vertical takeoff and landing capabilities.

While exploring the design space and implications of using rotorcraft for emergency and disaster response is not new [Ref 1], there are few projects within this domain at NASA that are actively funded. One project called ACERO [Ref 2], Advanced Capabilities for

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Emergency Response Operations, aims to develop new aircraft traffic management software to help UAVs navigate the airspace safely in active wildfire relief efforts. One work that has started to explore the design space and implications of using existing rotorcraft for public good missions was funded under the Revolutionary Vertical Lift Technology Project, RVLT [Ref 3]. This work is built upon and expanded in another paper submitted to this technical meeting [Ref 4]. While the work by Silva and Solis expands upon the design of a specific wildfire resupply mission vehicle, this paper will give a broader overview of multiple missions and their potential dual-use between civilian and military applications.

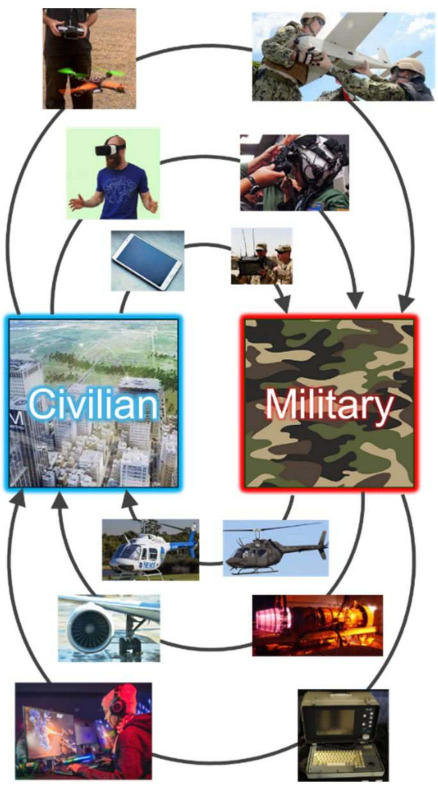

Figure 1: Civilian versus military technology diagram (top reads left to right, bottom reads right to left; clockwise).

Another paper submitted to this technical meeting discusses the opportunities and challenges for several different disaster relief and emergency response missions for rotorcraft, as well as the networks and logistics that exist within them [Ref 5]. While that paper mentions the potential dual-use between military and civilian UAVs, this paper focuses on that topic and goes into more detail on specific opportunities and the logistics required to implement the system.

Two years ago, the VAERA team published a paper identifying technology gaps for wildfire relief rotorcraft missions [Ref 6]. More recent papers have been published on analyzing handling qualities and power consumption for UAM eVTOL quadrotors in a simulated wildfire environment [Ref 7], and using AAM rotorcraft tools for wildfire applications [Ref 8]. During VAERA's research over the past 6+ years, the VAERA team has observed that a significant technology gap for rotorcraft is the ability to maintain adequate handling and flying qualities within turbulent environments (e.g. the wildfire environment). Several emergency and disaster environments (e.g. hurricanes, tsunami, floods, etc.) often come with extreme weather. This paper will seek to continue the work of identifying technology gaps for rotorcraft in emergency response and disaster relief scenarios.

DUAL-USE UAS APPLICATIONS

Multiple opportunities for dual-use applications present themselves from only a cursory review of existing military and civilian drone attributes and applications. Table 1 deconstructs the basic mission functions into Delivery (bringing people or supplies to a site), Transport (picking people or supplies up from a site), and Surveillance (observation of a general area or a specific site). Notably, Table 1 contains roles where drones are already in use (e.g. military and civilian observation) and roles where their application is hypothesized (e.g. MEDEVAC and rescue), with overlap of vehicle attributes already evident to support the argument for dual-use platforms.

Table 1. Overlap in select dual-use rotorcraft missions for eVTOL and UAS rotorcraft

(■Civilian ■Military ■Crewed ■UAS)

Function	Application	Use Cases
Delivery	Logistics	■Civilian ■Military ■Crewed ■UAS
	Emergency Supply	■Civilian ■Military ■Crewed ■UAS
	Consumer	■Civilian ■UAS
Transport	Air Taxi	■Civilian ■Crewed ■UAS
	MEDEVAC	■Military ■Crewed ■UAS
	Search & Rescue	■Civilian ■Military ■Crewed ■UAS
	Tactical	■Civilian ■Military ■Crewed
Observation / Surveillance	Law Enforcement	■Civilian ■Crewed ■UAS
	Disaster Response	■Civilian ■Military ■Crewed ■UAS
	Reconnaissance	■Military ■Crewed ■UAS

In the fields of UAM and AAM, public and commercial surveys have identified similar functions to those in Table 1 as possible secondary roles of eVTOL air taxis [Refs. 9, 10]. Seeking near-term low risk payoffs for dual-use platforms, this study refocuses below the 2,000+ pound weight class of eVTOL transports and makes the following observations and hypotheses in the Group 2-3 range of UAS systems below 100 pounds:

1. Multicopters fill a large market share of dual-use observation missions in the Group 2 category, with growing interest in resupply applications above 55 pounds in Group 3. Presently, conventional helicopters perform some of the roles in Table 1, but a Group 2-3 dual-use platform could do the same work more affordably.

2. Operated as part of a system of dual-use platforms, UAVs in the high Group 2 or low Group 3 size class could augment existing aviation assets and future UAM / AAM assets.

To understand the design drivers of a hypothetical dual-use uncrewed aerial system (UAS) as it might fit into these objectives, mission task elements of dual-use missions should be considered by role in relation to their design effects for surveillance, delivery (cargo/resupply), and transport missions.

Surveillance

Surveillance applications are perhaps the most popular uses for drones and uncrewed aerial vehicles both in civilian and military applications. Several industry applications are gaining popularity as well from surveying crops in agricultural applications to using tracking features on moving objects in the film industry. Attributes of these missions, especially reliability and maneuverability, align well with firefighting support in terms of observation and monitoring of wildfires presently handled by conventionally crewed aircraft. These performance attributes would also align well to support search and rescue missions related to avalanches, landslides, maritime operations, and post-disaster damage assessment and survivor location. Below is a list of different public good surveillance missions:

- Wildfire relief efforts
  - Before a wildfire is reported, surveillance drones can be deployed in high fire risk areas to help catch fires when they first start.
  - During an active wildfire, surveillance drones can be deployed outside of the crowded airspace, as to not interfere with waterdrop vehicles, and survey the areas just outside the fire to help find small spot fires started by jumping/flying embers carried on the wind.
  - During an active wildfire, can have an aerial drone loitering above a ground crew to give them an aerial view of their surroundings and warn them of approaching dangers (fire changing direction, falling trees, etc.).
  - During an urban fire, having an aerial view of the active fire zone could be very useful to firefighters on the ground.
- Avalanche in snow/mountainous areas:
  - Before an avalanche, can deploy drones to help determine high avalanche risk areas.
  - Once avalanche occurs, can quickly deploy drone with thermal camera to help determine location of any humans trapped in the snow.
- Shipwreck or sinking ship:
  - An active shipwreck situation can be dynamic and change quickly. Having active surveillance of the situation from a drone that is out of the way could be critical for relaying information to emergency personnel.
- Mudslide:
  - If there is a mudslide going over a major street or highway, having a stationary surveillance drone to help monitor the situation would be beneficial to emergency services.
- General post disaster relief:
  - After any disaster, weather permitting, a drone can be dispatched to survey the area to help assess the damage and to help locate any survivors. This can be applied towards relief efforts for earthquakes, tsunamis, floods, and storms just to name a few.

Figure 2: Search and rescue drone looking for survivors after flood. (AI generated image).

Some of the most important characteristics of a surveillance drone are endurance (how long can it fly) and the quality of the surveillance footage. The endurance of the drone will come down to the batteries, the efficiency of the rotor system, and the environment (e.g. if there are turbulent winds, the drone has to use its energy to stabilize). The quality of the surveillance footage is determined by the cameras, the transfer mechanism, and the environment. If the cameras are not equipped to handle extreme turbulence, the quality of the surveillance may be at risk. Additionally for certain missions, an infrared camera may be desired. Depending on if the surveillance mission is roaming versus stationary, the drone should either be optimized for cruise or hover. It is possible that this "optimization" may be achieved with the same drone by swapping out the rotors.

Delivery and Transport

Delivery applications are equally pertinent to public good and military missions. The VAERA team [Ref. 6] has researched various wildfire resupply missions delivering equipment, food, and medical supplies, which could decrease firefighter workload and physical load, and increase crew productivity. Often, firefighters will hike several miles into the forest to dig firelines or do controlled burns, potentially working/remaining in the forest overnight. A drone could help carry some of the tools, replace broken tools, and drop off food and water. Reducing the amount of equipment carried on foot is a substantial benefit in terms of reduced fatigue. Additionally, if there is a medical emergency, the drone could quickly deliver the emergency medical supplies to the firefighters.

Humanitarian aid delivery represents a similar opportunity for increased productivity and reduced cost in both scheduled and unscheduled operations to remote areas. Removal and repositioning support of spent water and fuel tanks and debris from disaster areas represents the accompanying second half of the delivery equation.

Another mission case to consider is relief after an earthquake. A drone with the ability to move objects could help clear debris and rubble from a building affected by the earthquake without risking human life. As mentioned earlier, a roaming surveillance drone could be used post earthquake to assess the damage to a site, and then this payload transport drone could help with clearing the paths and buildings that are not safe for people.

An evacuation drone (drone that could pick up and move people from an unsafe location to a safe location) could help during a shipwreck, fire, or flood, an evacuation. For this specific mission, having a crewed vehicle could be more beneficial for real-time decisions, but having an uncrewed vehicle with a human in the loop would reduce weight, enable the aircraft to rescue one additional person.

Drone delivery of equipment, fuel, food, water, or medicine in public good missions aligns closely with existing military logistical missions such as uncrewed logistics system-air (ULS-A) and tactical resupply UAS (TRUAS) [Ref 12], although military requirements aim for heavier loads – with a minimum of 60 pounds payload deliverable at 10 nautical miles.

DESIGN CONSIDERATIONS AND METHODS

Requirements

It is useful to frame the discussion of Group 2-3 dual-use UAS applications with a design example quantifying the feasible space, weight, power, and cost outcomes along with technology and analysis needs. The design and performance of a sized concept vehicle can serve to set expectations for requirements as well as to identify existing platforms with similar attributes which are already in production. The NASA Design and Assessment of Rotorcraft Code (NDARC) [Ref 13] requires a set of performance requirements and technology assumptions to size a vehicle.

This study targets an intermediate multicopter design with more capability than current commercial off-the-shelf (COTS) observation drones of 20 pounds or less while staying below the $300,000 unit price of uncrewed military platforms in the 300+ pound weight range such as the ULS-A / TRUAS logistics drone [Ref 12] as well as light single engine turbine helicopters in the $2-3 million price range. Recognizing that a viable dual-use UAS requires communication and all-weather capability beyond COTS multicopters, the study also seeks to incorporate sufficient design margin for operations in austere conditions while also keeping core vehicle weight below 55 lb to give operators the flexibility to fly within the less restrictive Part 107 Small UAS allowance if desired [Ref 12]. Professional operators in need of greater payload and range could alternatively fly such a vehicle at higher gross weight using the exemptions provisions in 49 U.S.C. 44807 [Ref 14].

Research was performed to define the equipment used in ground and air operations for the roles shown in Table 1. Restricting the list to items less than 30 pounds (half of the minimum Army/Marine ULS-A payload), the pacing items of potential interest for firefighting support, disaster relief, and search and rescue which emerge are summarized in Table 2, with greater detail added in Table 7.

Several payloads from Table 2 could be air-dropped from low altitude or unloaded from a vehicle after landing. However, considering the added flexibility of a direct offload from a hovering aircraft, the decision was made to include a winch system in the payload weight and size the resupply mission around a cable-dropped delivery from the vehicle stationary in a 20-30 foot hover above ground level. The maximum payload for a delivery mission is thus 31.8 pounds. As mentioned, using approximately 30 lb as the primary vehicle sizing payload provides scope for the current study while also preserving the possibility of two dual-use platforms at this performance point successfully team lifting (multiple drones working together to lift an object) a full 60 lb ULS-A payload.

Table 2. Dual-use payloads used in vehicle sizing, length and width-defining payloads in *italics*

Item	Weight (lb)	Length (ft)	Width (ft)
6-Person Raft	25.00	1.38	1.08
Water Pump	20.10	1.17	0.90
EMT Bag	13.00	1.50	1.08
Life-Preserver	*1.36*	*2.50*	*2.50*
Firefighting Tool	*5.50*	*4.00*	*0.81*
Winch Sys.	6.80	1.44*	0.48*
EO/IR Sensor	5.80	0.50	0.50

italics indicate length-pacing payload items
*est. quantity

Length and width of payload items were also surveyed in comparison to external cargo space of COTS delivery drones. Fig. 3 shows projected vertical fuselage and rotor disk areas of three cargo drone platforms, illustrating that the current maximum operating footprint is approximately 11×11 feet in length and width, with approximately 4×4 feet of stowage space directly underneath the vehicle body (red line in Fig. 3). Allowing for a degree of advantageous payload packaging, initial bounding assumptions are made that the example dual use vehicle will fit inside the form factor of existing delivery platforms; and no payload items will protrude beyond the total vehicle operating footprint; and at least 40% of the maximum payload length will be covered by the fuselage.

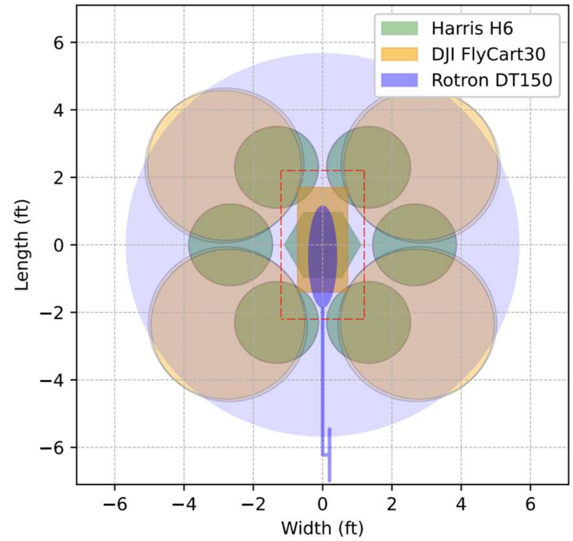

Figure 3. Delivery drone operating footprints and desired dual-use attachment payload space (red).

Weight Assessment Methods

Conceptual design of a multicopter airframe with specific consideration given to the projected area as in Figure 3 requires a means of weight prediction linking the dimensions of the central body (inside the rotors) to the weight of the fuselage group. To this end, multicopter platforms with published component weights were surveyed to develop a new equation for the body group.

For the purposes of this assessment, the empty weight of a multicopter is simplified to Eqn. 1:

$$\mathrm{WE_{mc}} = \mathrm{W_{body}} + \mathrm{W_{batt}} + \mathrm{W_{motor}} + \mathrm{W_{ESC}} + \mathrm{W_{rotor}} \quad (1)$$

The body weight is understood to include the weight of rotor arms and landing gear if present (some multicopter designs include no landing gear or minimal landing gear integrated into the fuselage or rotor arms). The empty weight does not include external mission equipment such as cameras and sensors, but some minimal residual avionics and wiring weight may be captured in the body group as it is expressed in this method. The predicted weight w_{body} in pounds as a function of maximum fuselage length ℓ_{fuse} and width w_{fuse} is then given as

$$w_{body} = 4.702\,(f_{proj}\,\ell_{fuse}\,w_{fuse})^{1.2930} \qquad (2)$$

for quadcopters (4 rotors) less than 9 pounds in total gross weight and shorter than 1 foot in length, with a average absolute error of 25.3% over 6 examples. For multicopters greater than 8 pounds gross weight, the predicted body group weight is

$$w_{body} = 6.056\,(f_{proj}\,\ell_{fuse}\,w_{fuse})^{1.4306} \times N_{point}^{0.1343} \quad (3)$$

with an average absolute error of 19.2% over 12 examples. In Eqn. 3, N_{point} denotes the number of arms or body corners supporting a rotor assembly ($N_{point} = 4$ for a quadcopter, 6 for a hexacopter, and 4 for an octocopter with each arm supporting 2 stacked rotors). In both equations, f_{proj} is frequently equal to 1.0, but can be used to adjust the projected fuselage area if it is not a well-defined polygon shape as described by the maximum length and width terms, or when the rotor arms are uncharacteristically long.

Configuration Selection

Although commercial drone manufacturers offer multiple configurations capable of flying dual-use missions, this study makes several design assumptions based on qualitative assumptions for the sake of bounding the scope of the analysis to one example configuration. For the sake of redundancy and safety of flight over inhabited areas, a 6-propeller hexacopter configuration is employed. Battery electric propulsion is used exclusively for simplicity of operations at this weight class, although future work could consider payload trades which include gasoline or fuel cell generators for range extension.

The sizing and off-design mission performance assessment assumes the battery weight is tradeable with payload weight. This implies that the propulsion system is operable on one baseline battery or an expanded pack of multiple batteries without performance degradation in any condition. This requires a parallel arrangement of high voltage (greater than 44 volts per pack) batteries, preferably with the highest possible system-level energy density (greater than 300 Watt-hours per kilogram). While modern lithium-polymer batteries meeting these requirements are available [Ref. 15], additional cost beyond typical COTS drones is accepted as a necessity by this decision.

Mission Profiles

Requirements for a Group 2-3 remotely piloted UAS tend to focus on a 10 nautical mile operating radius (Ref. 11). Since delivery missions are expected to be driven by vehicle gross weight and installed power, while observation missions are expected to be driven by battery size, the study employs a sizing strategy focused on modularity. Shown in Fig. 4, a 10 nautical mile delivery mission with the 32 lb target payload, sizes vehicle gross weight.

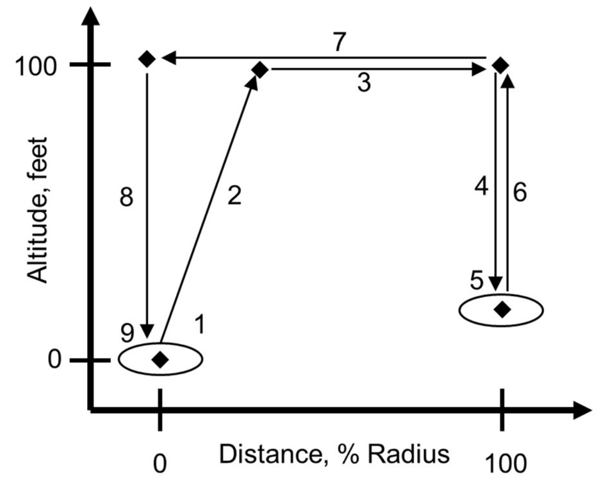

Fig. 4. Hover cargo delivery mission profile (battery sizing mission).

An observation mission which omits the midpoint hover segment in favor of a loiter at best endurance speed is evaluated as fallout (not sized) capability using the installed energy of the baseline battery pack, but the endurance is reevaluated for multiple levels of payload tradeoff in exchange for additional battery packs. From the original study objectives, mission performance in the observation role was also evaluated at 55 pounds gross weight to track the capability while operating within Group 2 limits.

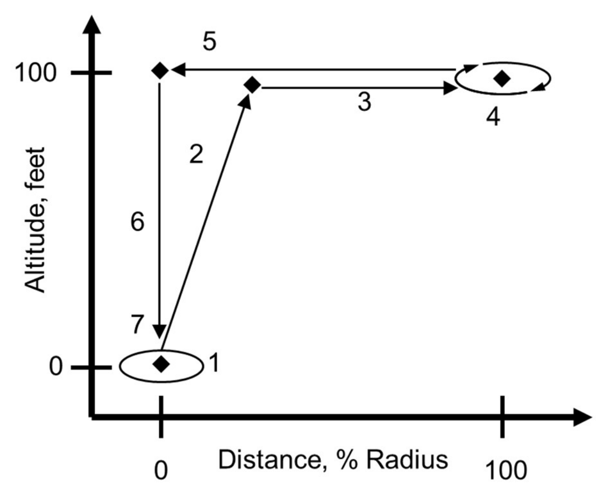

Figure 5. Observation mission profile (battery fallout capability).

PLATFORM EVALUATION

Vehicle Sizing

Besides the fuselage weight assessment developed in Eqns. 2 and 3, vehicle technology assumptions were derived from supporting market research in Ref. 14 to reflect modern Group 2-3 uncrewed aircraft. Overall, the operating footprint of the resulting hexagonal design shown in Fig. 6 is confined within the dimensions of existing heavy lift electric drones.

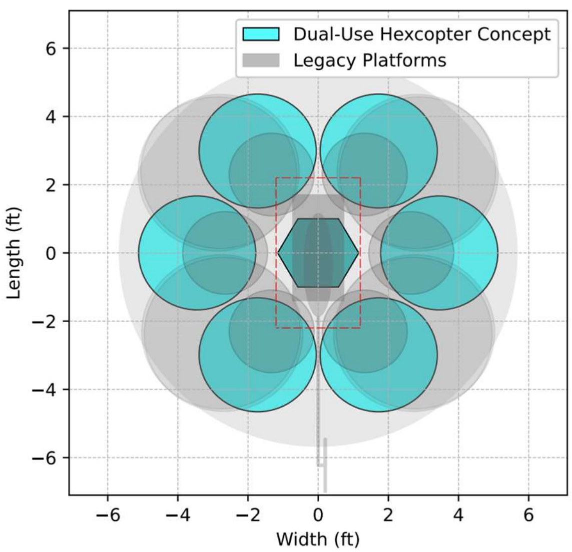

Figure 6. Dual-use concept op. footprint compared to legacy platforms and payload mounting (red).

Rotor radius is larger compared to existing 6-rotor designs but is fixed at 1.75 feet with clearance separation slightly reduced. Fuselage width increased by less 10% to provide additional payload and battery volume while limiting structural weight growth. The resulting configuration shown exhibits a much larger percentage of the total operating footprint filled by rotor disk area. Rotor in-plane clearance is slightly reduced, possibly introducing interference effects for future configurational research.

Table 3 summarizes the dual-use concept vehicle's design characteristics at two operating points. Significantly, the core airworthy vehicle with the minimum necessary complement of first-person video capability and data link communications for line of sight operation has a total weight less than 55 pounds, allowing for operations within the Federal Aviation Administration (FAA) Group 2 UAS waiver authority. At an alternate vehicle weight including the objective 32 pound cargo payload, the vehicle gross weight is 86.7 pounds.

Table 3. Estimated dual-use hexacopter design characteristics from sizing routine

Item		Group 2 Vehicle (< 55 lb)	Alternate Gross Wt. (Group 3)
Gross Weight	lb	54.9	86.7
Op. Empty Wt.	lb	54.9	54.9
Mission Payload	lb	0.0	31.8
Installed Power	hp	9.6	9.6
Rotor Radius	ft	1.67	1.67
Disk Loading	lb/ft^2	1.04	1.65
Vehicle Drag, *D/q*	ft^2	2.15	2.15
Fuselage Length	ft	2.0	2.0
Fuselage Width	ft	2.3	2.3
Operating Length	ft	9.3	9.3
Operating Width	ft	10.2	10.2
Max. Speed	kt	44	44
Best Range Speed	kt	35	38
Loiter Speed	kt	26	28

Table 4 and Figure 5 detail the tradeoff of payload mass between the Group 2 and Alternate Objective gross weights. Relaxing mission requirements to half of the objective payload, significant resupply capacity is still deliverable at 22 nautical miles distance, which covers all but two of the identified payload items in Table 2. For the generic observation mission (Table 5), converting the useful load to additional battery mass results in almost 1.5 hours of station time while employing a high performance electro-optical/infrared sensor for situation awareness.

Table 4. Cargo Resupply Mission Performance at Design Gross Weight (86.7 lb)

N_{batt}	1	2	3
W_{batt}, lb	15.8	31.6	47.4
Payload, lb	31.8	16.0	0
Max Radius, nm	9.6	22.0	34.7

Table 5. Cargo Resupply Mission Performance with sensor payload and 2 batteries

Radius (nm)	0	8	16	24
Time on Station (mins)	85	57	28	0

Dual-use uncrewed systems will ideally supplement, but not replace conventional rotorcraft in public good VTOL roles. Allowing for the much greater payload and flight time of a light single engine turbine helicopter, it is still useful to compare overall vehicle flyaway and operating cost as a means of promoting smaller dual-use platforms in roles where they are right-sized to offload tasks from higher value assets at reduced cost and risk. Table 6 compares the approximate purchase price and direct commercial variable cost per flight hour of a representative single engine turbine helicopter such as the Bell 407 or Airbus H125 to the dual-use hexacopter's cost as estimated using the methods from Ref. 11. The operating costs, described in greater detail in Table 7, are formulated to represent what a commercial customer might pay in lease rates from an aviation service.

In both cases, substantial cost savings are observed from the piloted helicopter solution if the dual-use platform's capabilities are a viable substitute. Flyaway cost and variable operating cost are each reduced by approximately one order of magnitude. Considering the difference in flyaway cost, operating cost would show an even larger reduction if financing costs were included in the analysis.

Table 6. Price range comparison - Equipped Unit Flyaway in USD (2025)

	Single Eng Helicopter	Dual-Use Hexacopter Drone
Weight Class	2,000 – 3,000 lb	55 – 87 lb
Unit Flyaway	$2.5 - 3.5 Mil.	$45 – 55k
Cost per Flight Hour	$1,483	$54.55

DRONE FLEET DELIVERY

One concept that this paper aims to explore is delivering a large fleet of drones to aid in disaster or humanitarian relief via 1) an aircraft carrier or 2) a large military airplane.

One case for a large aircraft carrier would be to provide humanitarian aid/relief after a disaster. If there was a tsunami struck area, the shipping ports would likely not be usable and even if supplies were shipped over, they might not be able to be received. If a fleet of drones was shipped along with the emergency supplies, then the supplies could be flown in and delivered with the drones. This could be useful for regions close to the coast, or islands. These delivery drones could be used alongside the payload transport drones to help clear debris from the aftermath of the tsunami.

One case for a large military airplane would be for an active disaster. The military airplane could load up a fleet of supply, surveillance, transport, and rescue drones. When the plane flies over to the active disaster site, it could open the cargo doors and the drones would then takeoff from the air and perform their respective missions. For example, during a flood, surveillance drones could provide necessary information to first responders to help locate stranded people, locate any danger zones, and help identify useable roads. Supply drones could help deliver equipment to first responders if the roads are flooded. Transport drones could help clear up the roads and move supplies to safe areas. Additionally, rescue drones could help rescue stranded people in areas unsafe for first responders. The assumptions made in the sizing cargo mission of this study allow for both of these employment methods.

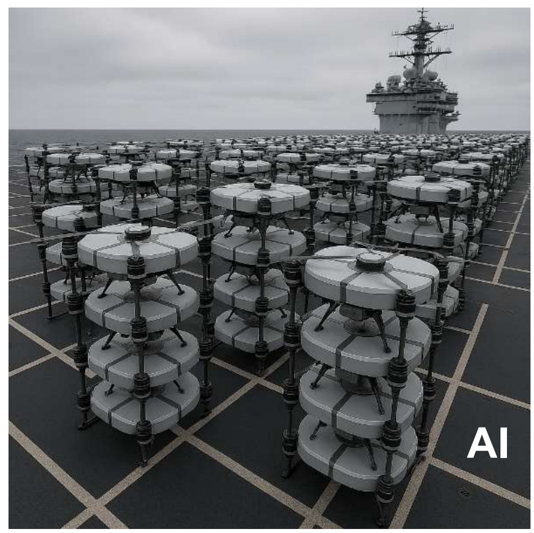

Figure 7. Drones stacked and ready for transport on aircraft carrier. (AI generated image)

For both of these large drone fleet delivery methods, there are several considerations that need to be taken into account. If the drones are able to be packaged up tightly during transport, then a greater number of drones could be shipped in or flown in to the disaster site. For the aircraft carrier or large ship scenario, having multiple landing pad areas would be ideal for carrying out multiple missions at a time, rather than sending only one drone out at a time. For the large airplane drone delivery method, if the drones are dropped mid-flight from the airplane, the drones will have to be in a configuration that would allow them to fly. This means that if they are packaged up in a box, they would need to be removed from said box and perhaps assembled (if the assembly cannot be done automatically while dropping from the plane in mid-air).

Another consideration for these drone fleets is the air traffic management of these drones once they are deployed. If there are tens or hundreds of drones operating in an airspace of a disaster site, that could add to the already congested airspace. A system needs to be in place to handle all of those drones before they are inserted into the airspace. It is imperative that local and federal emergency service personnel are included in planning and implementation discussions for these mission concepts.

One of the major considerations for these missions is where these drones are going to come from and who is going to pay for them. There are several drones and UAVs already in military and industrial inventories, as well as in the hands of civilian and amateur operators, that could be given to local or federal government in times of emergency and natural disasters. A collaborative drone network among government agencies could be set up to facilitate transfer of function ("drafting") among stakeholders, whether among civilian users or between government agencies if technology, applications, and regulations allow for a future ecosystem of dual-use platforms with broad applicability

CONCLUSIONS

This paper discussed the design considerations for and presented a conceptual dual-use vehicle that could be used for a cargo/resupply mission and a surveillance mission, where the mission details were aligned with public good efforts. Additionally, this paper provided a survey and discussion of several public good missions that could utilize dual-use UAVs, and various considerations for implementing those platforms.

Using available low risk assumptions within the limits of near-term technology, this study suggests a viable case may exist for an electric multicopter in the intermediate operating space between Group 2 platforms and heavy UAS and conventional rotorcraft. By strategically selecting vehicle dimensions and propulsion system design conditions to operate across size categories and roles, the applicability of the identified hexacopter configuration is increased while retaining economic assumptions representative of high-end COTS systems.

Since some in-production UAS platforms do exist in close proximity above and below the study's selected design point, this raises a question of why dual-use technology has not been pursued further at the present time. Ultimately, deeper market adoption may simply require time, as the UAS and dual-use technology ecosystems evolve. Creative means of employment, particularly the integrated operation of dual-use platforms as systems of systems, some of which is speculated upon in this study, may be key to unlocking greater productivity in the transformative vertical flight field.

In the farther future, drones are speculated to fill a role of assisting in the evacuation of disaster areas and conflict zones. Dual-use vehicles could significantly increase the impact of the relief effort for emergency and disaster response, saving more lives and making our world a safer place.

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Table 7. Estimated dual-use hexacopter weight by component group.

	Weight (lb)
Weight Empty	54.9
Structure	28.9
Rotor	*3.6*
Fuselage + LG	*25.3*
Propulsion	22.0
Motors	*5.5*
Battery (1 pack)	*15.8*
Wiring	*0.6*
Systems & Equip.	1.7
Environmental Cntrl.	*0.5*
De-ice	*0.5*
MEQ – Autopilot	*0.1*
MEQ – Comms	*0.2*
MEQ – Nav	*0.2*
Load & Handling	*0.2*
Contingency	2.7
Weight Empty	54.9
Payload	31.8
Design Gross Weight	86.7

Table 8. Extended list of representative payloads for dual use resupply missions

Item	Weight (lb)	Length (ft)	Width (ft)
Firefighting			
McLeod Tool	5.5	4.0	0.8
Pulaski Axe	8.8	3.0	1.0
Chainsaw	18.1	2.9	0.8
Personal Fire Shelter	4.6	0.7	0.3
Portable Water Pump	20.1	1.2	1.0
Disaster Relief			
Temporary Shelter	12.1	2.0	1.3
Inflatable Raft (6 Person)	25.0	1.4	1.1
Inflatable Raft (4 Person)	16.0	1.3	1.1
Emergency Response			
EMT Bag	13.0	1.5	1.1
Portable AED	3.3	0.6	0.7
Type I Life Pres. Jacket	2.3	4.8	2.5
Life Pres. Ring (30 inch)	2.5	2.5	2.5
Life Pres. Ring (24 inch)	1.4	2.0	2.0
Observation			
EO/IR Sensor[1]	5.8	0.5	0.5
Military Logistics			
ULS-A Small Payload	60.0	N/A	N/A
ULS-A Medium Payload	300.0	N/A	N/A
ULS-A Large Payload	1,000.0	N/A	N/A

[1] [Ref 19]

Table 9. Comparison of avg, light single engine helicopter variable operating cost per flight hour

	Single Eng Helicopter	Dual-Use Drone
Pilot	200	40.00
Fuel	400	--
Energy	--	1.72
Maintenance	500	7.73
Battery	--	*3.33*
Eng / Motor	--	*1.80*
Propellers	--	*0.60*
Support Equip.	50	*1.00*
Insurance	333	4.00
TOTAL	$1,483 / FH	$54.45 / FH

Table 10. Generic light single engine turbine estimated operating cost [Ref]

	Cost per Flight Hour	
Fuel	400	100 gal/FH @ $4/gal
Maintenance	500	[Ref 16]
Pilot	200	$120k/yr, 300 FH/yr
Insurance	333	$100,000/yr, 300 FH/yr
Support Equip.	50	10% of Maintenance
Total $/FH	1,483	

Table 11. Dual-use hexacopter est. operating cost

	Cost per Flight Hour	
Energy	1.72	$0.35/kWhr,
Maintenance	7.73	
Battery[1]	*3.33*	N_{charge} = 1,000 Cycles
Motor[2]	*1.80*	MTBR = 1,000 FH
Propellers[3]	*0.60*	MTBR = 500 FH
Airframe[4]	*2.00*	3,000 FH airframe life
Pilot	40.00	Drone operator rates
Insurance	4.00	$12,000/yr, 300 FH/yr
Support Equip.	1.00	50% of airframe maint.
Total $/FH	54.45	

[1] $2,500 battery cost, 2 batteries in nominal operation, 80% of rated energy used in a 90 min mission
[2] $300 motor cost, 6 motors per aircraft
[3] $50 blade set cost, 6 sets per aircraft
[4] Allowance held for total replacement within 10 years

Table 12. Cargo Resupply Mission – baseline battery sizing mission.

	Segment Kind	Time (mins)	Distance (naut. mi.)	Speed (kt)	ROC (ft/min)	Atmosphere (alt / temp)	Notes
1	Hover	1.0	--	--	--	0 ft / 103°F	
2	Climb	--	--	Best Climb	500	103°F	
3	Cruise	--	10.0	Best Range	--	100 ft / 103°F	
4	Descend	--	--	--	-200	103°F	
5	Hover	5.0	--	--	--	20 ft / 103°F	Cargo delivery (winch)
6	Climb	--	--	Best Climb	500	103°F	
7	Cruise	--	10.0	Best Range	--	100 ft / 103°F	Cargo wt. retained*
8	Descend / Loiter	--	--	Best End.	-200	103°F	
9	Hover	1.0	--	--	--	0 ft / 103°F	Reserve*
	Design Conditions						
	Vert. Climb	90% MCP		--	600	0 ft/ 103°F	Size Motors
	Cruise Climb	100% MCP		30	500	0 ft/ 103°F	Use % Margin of hardest working motor

*The full mission cargo weight is retained for the return cruise segment to emulate either an unsuccesful delivery attempt or a delivery combined with a repositioning or removal activity.

*Battery reserve calculated in Segment 9 is in addition to 20% battery margin in state of charge (SoC) preserved at fuel tank sizing missions

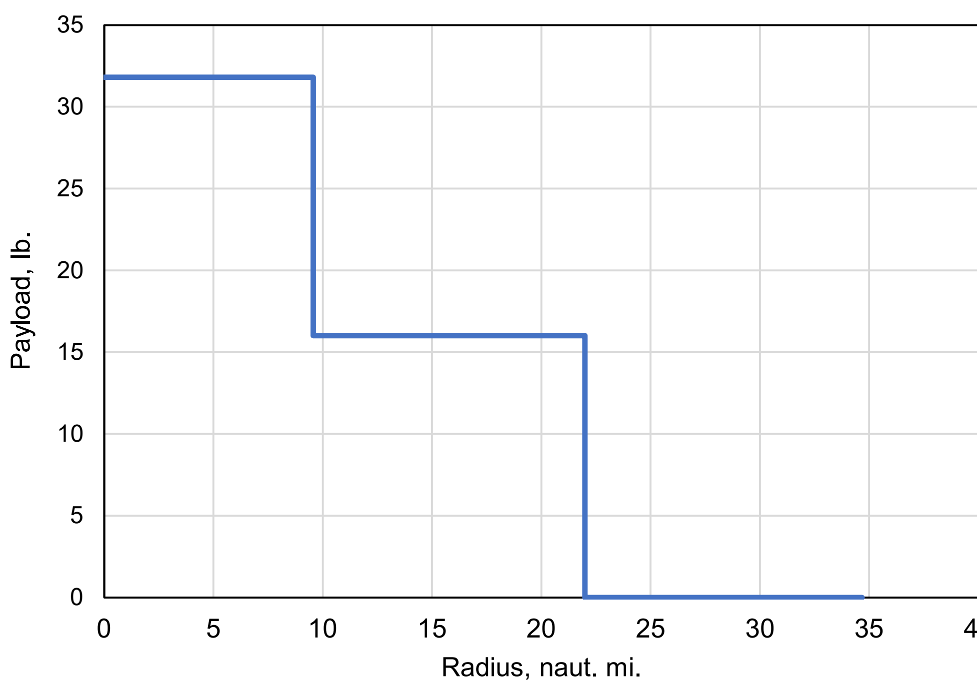

Figure 8. Cargo delivery mission range-payload profile, flown at dual-use design gross weight (86.7 lb).

Table 13. Observation Mission profile

	Segment Kind	Time (mins)	Distance (naut. mi.)	Speed (kt)	ROC (ft/min)	Atmosphere (alt / temp)	Notes
1	Hover	1.0	--	--	--	0 ft / 103°F	
2	Climb	--	--	Best Climb	500	103°F	
3	Cruise	--	10.0	Best Range	--	100 ft / 103°F	
5	Loiter	fallout	--	Best End.	--	100 ft / 103°F	*Mission object point
6	Climb	--	--	Best Climb	500	103°F	
7	Cruise	--	10.0	Best Range	--	100 ft / 103°F	
8	Descend / Loiter	--	--	Best End.	-200	103°F	
9	Hover	1.0	--	--	--	0 ft / 103°F	Reserve

*Accessory power for EO/IR sensor is assumed on throughout all mission segments in addition to time on station at mission objective point (search operations begin en-route).

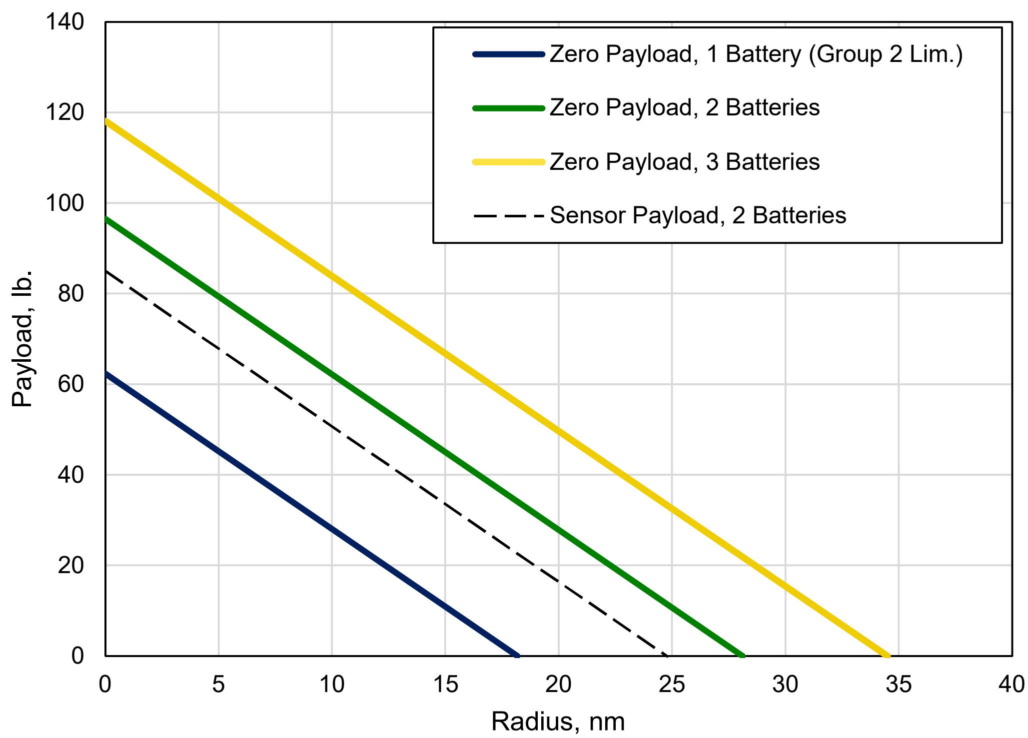

Figure 9. Radius – time on station tradeability in generic observation profile, including line of sight operations (solid) and over the horizon capability with 5.3 pound EO/IR sensor, P_{acc} = 70 Watt (dashed)