ENVIRONMENTAL ISSUES OF AERIAL DRONE ACTIVITIES

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Introduction

In a society of full questioning on the climatic stakes, the place of air transport is the subject of debate and a consensus is emerging on the need to reduce its impact on the environment and in particular its contribution to climate change.

Greenhouse gas emissions (mainly carbon dioxide or CO2) linked to human activity, to which aviation has contributed about 3% over the last 20 years, contribute to climate change by permanently modifying the planet's effective radiative forcing. These emissions must radically change and decrease by about 7% per year to hope to contain the warming of the atmosphere to +1.5°C compared to pre-industrial levels.

At the same time, all market studies predict strong growth in the drone industry, whose sales could increase by two orders of magnitude by 2030. This growth is supported by the emergence of new technologies that will allow for elongation flights, facilitate the insertion of drones into the airspace, and allow the safe overflight of populated areas.

In an attempt to understand this apparent contradiction between the growth of drone activity and the need to control the impact of aviation activities on the environment, this document has been written by DAHER's technical team, at the request of the Association des Drones de l'Industrie Française (ADIF), whose commitment to the ecological transition is one of its core values.

Preamble

As with all aerial operations, it is necessary to question the use of drones with regard to environmental issues. While some uses are unquestionably useful for environmental protection of the environment (such as securing industrial sites or helping to reduce the use of pesticides in reduction of pesticides in agriculture), or constitute an undeniable progress for the protection of people (such as the delivery of medical equipment or foodstuffs in case of unavailability of land transport), this is not the case for some other uses, such as the delivery of consumer products by drones, which would be promoted on the grounds that it would be faster than other less energy-intensive means of ground transportation.

In the rest of the document, it will be assumed that the aerial operations studied are justified with respect to climate issues.

The analysis is focused on greenhouse gas emissions, even if other nuisances that impact the environment and living beings could be analyzed in the same way (such as noise pollution or collisions with birds).

It covers the activities of UAVs operating at low and medium altitudes for surveillance and logistical transport missions. It excludes the potential activities of passenger transport drones, armed drones, and armed UAVs, as well as surveillance UAVs operating at high altitude and which could be affected by contrails.

Theoretical approach and case studies

The studied light aircraft contribute essentially to the greenhouse effect of the earth's atmosphere through the amount of CO2 emitted during their construction, operation and dismantling.

The amount of CO2 emitted during the operation of an aircraft is directly related to the amount of energy consumed to perform the mission, while the amount of CO2 emitted during its construction and dismantling is directly related to its empty weight and the nature of the materials it is made of.

Theoretically, drones sized to the right requirements can carry out aerial missions with less energy consumption than piloted airborne means with the same mission capacity, also sized according to need.

Indeed, the absence of pilots and of some comfort equipment allows to reduce the maximum take-off weight and consequently the maximum power of the propulsion system, which in fact reduces the energy demand for the mission.

Also, due to its lower empty mass, the energy requirement to build/operate/dismantle, and therefore the carbon footprint of a drone will theoretically be lower than that of an aircraft with equivalent mission capacity.

Thus, in theory, the lower the energy required for the mission, the greater the difference in carbon footprint in favor of the drone. The difference tends logically to decrease when the mass increases.

To illustrate this somewhat trivial theoretical approach, the case studies below allow to compare the CO2 emissions between, on the one hand, a drone optimized for the mission, and on the other hand a manned aircraft existing on the market and whose mission capabilities are as close as possible to the right need.

For transport missions, the payload is the difference between the take-off weight and the empty weight, while the payload is defined as the payload minus the weight of the pilots and the fuel at takeoff.

1- Surveillance mission in advance flight

For this 3-hour surveillance mission at 1000 ft for which hovering or very low speed flight is not required, two fixed-wing aircraft are compared:

- a drone sized to carry 3 kg of payload (Delair DT26 type)
- one of the smallest two-seater light aircraft available on the market (type Aeroprakt A22)

	
Delair DT26	Aeroprakt A22

The recommended cruising speed for the mission is between 30 and 40 kts.

In this case, the energy required to transport the payload is low enough that the drone can be equipped with an electric motorization, whereas the plane must be satisfied for the moment with a thermal engine, while waiting for the arrival of other technologies potentially more favorable in terms of CO2 emissions.

Type	Engine / Fuel	Power max	Empty weight	CO2 for the mission[1]	Carbon footprint GHG Production & End of Life[2]	Carbon footprint mission + production & end of life[3]

Fixed wing drone	Electric/ Battery	1 kW	16 kg	0,4 kg	432 kg	1 kg
ULM fixed wing	Pistons / AVGAS	73,5 kW	331 kg	82 kg	8937 kg	84 kg

1 Emissions in equivalent kg of CO2, calculated over 3h at the optimal speed of fuel economy (59kt for the ULM, 31kt for the Drone) and with the following references:
- *1 kg of AVGAS burned = 3.77 kg eq-CO2 (direct and indirect emissions, calculated in the European perimeter)*
- *1 kWh of electricity = 0.23 kg eq-CO2 (current European mix)*

2 Assumption of 27 kg eq-CO2 / kg of aircraft produced for a thermal aircraft (EcoInvent V2.2).
Parallel consideration of emissions related to battery production with the following references:
- *Energy density: 280 Wh/kg*
- *100kg eq-CO2 per kWh of battery produced (average order of magnitude between studies referenced by ICCT)*

➔ 28kg eq-CO2 / kg of battery (assuming product lifetime is shorter than battery lifetime, i.e. <4000h)
Emissions related to waste treatment are negligible in front of those related to production (0.015 kg eq-CO2 / kg of aircraft, EcoInvent V2.2 ➔ 5 kg eq-CO2 for ultralight), the surplus of emissions due to battery recycling is not taken into account.

3 Carbon footprint of production and end of life integrated into that of the mission by taking the lifespan of the aircraft.
Lifetime of 2000 hours for the fixed-wing UAV and 10,000 hours for the fixed-wing ultralight.

The CO2 emissions of the microlight during the mission are 205 times higher than those of the drone, while those related to construction and dismantling are 20 times higher (in proportion to the difference in mass).

The non-recurring part of the emissions in the calculation of the total emissions of the mission is 60% for the drone and 3% for the UAV and 3% for the microlight. The total emissions of the ultralight are 84 times higher than those of the drone.

In this example, the difference in engine type between the combustion engine aircraft and the electrically powered drone, due to the large difference in empty weight, has a very important impact on the carbon balance. A threshold effect appears in the relation between the energy needed for the mission and the level of CO2 emissions.

The ratio of the mission carbon footprints is attenuated when the footprint related to the construction and dismantling, although the conclusion remains the same.

Note 1: The constraint of the noise perceived on the ground imposes a minimal observation distance from the surveillance aircraft. In this case, the lighter electric drone will also be quieter (the noise level of a fixed-wing electric drone of the category studied here is about 53 dBA at 100 m distance). It will thus be able to get closer to the ground and thus reduce the mass of its payload, since the sensor will be lighter with a comparable recording accuracy. This favorable effect on the mass is however not of the same order of magnitude as that induced by the absence of a pilot.

Note 2: A UAV of the type studied here also constitutes a completely credible alternative to the multipurpose single-turbine helicopters which are used for missions 1bis of surveillance on fixed point. In this case, the UAV is positioned in a racetrack at a distance from the point to be observed (typically 1 to 5 km), and its optronic ball aims at the monitored scene. We can note moreover that the drone is undetectable at 1 km (it is generally not audible beyond 200 m of distance) when a helicopter, in spite of a heavy and powerful optronic ball is generally detected at 5 km.

For such a mission, the CO2 emission values for the drone remain the same. On the other hand, a typical single-engine helicopter weighs 1.3 tons (so 35,100 kg CO2 eq for the construction, compared to the 432 kg of the UAV) and consumes about 180 l of kerosene per hour of flight, that is to say 1361 kg CO2 eq for the mission compared to the 0.4 kg CO2 eq of the UAV.

By integrating the CO2 emissions linked to the construction, with the hypothesis that the lifespan of the helicopter is 20 000 h and that of the drone is 2000 h, we find a balance of 1 kg eq CO2 for the drone against 1363 kg eq CO2 for the helicopter, that is to say a ratio higher than 1000 between the two.

2- Surveillance and small logistics mission with hovering - Payload 20 kg

For this 3h surveillance mission for which hovering or very low speed flight is required, two motor aircrafts are compared:

- A drone just sized to carry the 20 kg payload over the requested duration (INDELA.I.N.SKY type)
- One of the smallest two-seater helicopters available on the market (type Cabri G2).

	

INDELA.I.N.SKY	Cabri G2

Both helicopters are equipped with a thermal piston engine.

The recommended cruise speed for the mission is between 20 and 30 kts at an altitude of 1000 ft. The energy required to transport the payload alone is about 0.7 MJ/kg[1*].

Type	Engine / Fuel	Power max	Empty weight	CO2 for the mission[1]	Energy consumed per kg of payload for the mission	Carbon footprint GHG Production & End of Life[2]	Carbon footprint mission + production & end of life[3]
Rotor drones	Pistons / AVGAS	26 kW	115 kg	73 kg	45 MJ/kg	3,1 t	82 kg
Very light helicopter	Pistons / AVGAS	110 kW	400 kg	316 kg	196 MJ/kg	10,8 t	327 kg

1. OPERATIONS
Emissions in kg of CO2 equivalent, calculated over 3 hours at the optimal fuel economy speed (38kt for the drone, 95kt for the helicopter) and with the reference of 3.77 kg eq-CO2 (direct and indirect emissions, calculated in the European perimeter) emitted per kg of AVGAS burned

2.PRODUCTION & END OF LIFE OF THE DEVICE
Assumption of 27 kg eq-CO2 / kg of aircraft produced for a thermal aircraft (EcoInvent V2.2). Emissions related to waste treatment are negligible compared to those related to production (0.015 kg eq-CO2 / kg of aircraft, EcoInvent V2.2)

3.Production & end of life carbon balance integrated in the mission carbon balance by taking the lifespan of the aircraft.
Lifetime of 1,000 hours for the rotary wing UAV and 3,000 hours for the light helicopter.

The CO2 emissions of the helicopter flown during the mission are 4.3 times higher than those of the drone, while those related to construction and dismantling are 3.5 times higher.

The non-recurring part of the emissions in the calculation of the total mission emissions is 11% for the drone and 3% for the helicopter. The total emissions of the piloted helicopter are 4 times higher than those of the UAV.

[1*] *Energy required ≈ energy lost theoretically for gliding flight.*
With a glide ratio of about 2 (helicopter) on a 3h trip at 25 kt → ~140km :
*Energy required ≈ 20 kg * 9.81 m/s2 * 70 km ≈ 14 MJ → 0.7 MJ/kg*

In this example, we observe the very significant impact on the carbon footprint of the empty weight penalty of the piloted helicopter compared to the UAV. The ratio of the mission's carbon footprint decreases slightly when the footprint related to the construction and dismantling is included.

3- Mixed surveillance and transport mission - Payload 150 kg and 1 m3

For this mixed transport mission of over 300 km of a 1 m3 low density package, two rotor aircrafts capable of landing and taking off without any particular infrastructure are compared:

- A drone just sized to carry the payload over the requested duration (of type Cabri G2 whose cockpit would have been transformed into a hold with a widened canopy, and whose the flight controls would have been moved to the rear bulkhead).
- One of the smallest 4-seater helicopters available on the market (type Robinson R44) whose copilot seat and the rear seats would have been arranged in the hold to be able to accommodate the payload.

	
Cabri G2	Robinson R44

Both helicopters are equipped with a thermal piston engine.

The recommended cruise speed for the mission is 65 kts at an altitude of 3000 ft. The speed for the calculation corresponds to the minimum consumption speed.

The energy necessary to transport the payload alone is approximately 0.27 MJ/kg[2*].

[2*] *Energy required ≈ energy lost theoretically for a gliding flight.*
With a glide ratio of about 10 (passenger plane) over a distance of 300km :
*Energy needed ≈ 150 kg * 9.81 m/s2 * 30 km ≈ 40 MJ ➔ 0.27 MJ/kg*

Type	Engine / Fuel	Power max	Empty weight	CO2 for the mission[1]	Energy consumed per kg of payload for the mission	Carbon footprint GHG Production & End of Life[2]	Carbon footprint mission + production & end of life[3]
Rotor drone	Pistons / AVGAS	110 kW	400 kg	201 kg	10 MJ/kg	10,8 t	207 kg
Very light helicopter	Pistons / AVGAS	160 kW	660 kg	253 kg	27 MJ/kg	18 t	262 kg

1. OPERATIONS
Emissions in kg of CO2 equivalent, calculated over 300km at the optimal fuel economy speed (95kt for the drone-helicopter, 105kt for the light helicopter) and with the following references
1 kg of AVGAS burned = 3.77 kg eq-CO2 (direct and indirect emissions, calculated in the European perimeter)
1 kg of Jet A = 3.83 kg eq-CO2 (direct and indirect emissions, calculated within the European perimeter)

2. PRODUCTION & END OF LIFE OF THE AIRCRAFT
Assumption of 27 kg eq-CO2 / kg of aircraft produced for a thermal aircraft (EcoInvent V2.2). Emissions related to waste treatment are negligible compared to those related to production (0.015 kg eq-CO2 / kg of aircraft, EcoInvent V2.2)

3.Carbon footprint of production and end of life integrated in the one of the mission by taking the life span of the aircraft.
Lifetime of 3,00 hours for the rotary wing UAV and 3,000 hours for the light helicopter.

The CO2 emissions of the helicopter flown during the mission are 1.3 times higher than those of the emissions, while those related to construction and dismantling are 1.7 times higher.

The non-recurring part of the emissions in the calculation of the total mission emissions is 3% for the UAV and 4% for the helicopter. The total emissions of the manned helicopter are 1.3 times higher than those of the UAV.

In this example, we observe the significant impact on the carbon footprint of the empty weight penalty of the piloted helicopter compared to the UAV, but this impact is smaller than in the previous example because of the smaller difference in empty weight.

Taking into account the production and dismantling carbon footprints has no effect on the ratio of the total carbon footprints.

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4- Payload transport mission 400 kg and 1 m3

For this mission of transporting a 1 m3 high density package over 300 km, three aircrafts are compared, all capable of landing and taking off without special infrastructure:

- A soft-wing drone just sized to carry the payload over the requested distance (of the Flying-Robot FR102 type)
- One of the smallest 4-seat helicopters available on the market and capable of carrying out the mission (Bell 505 type) whose copilot seat and rear seats would have been arranged in the in the cargo hold to be able to accommodate the payload
- One of the smallest cargo airplanes available on the market and capable of carrying out the mission without any transformation (type Cessna T206H Turbo Stationair "Utility" version)

		
Flying-Robots FR102	Bell 505	Cessna T206H Turbo Stationair

The soft-wing drone and the airplane are equipped with a piston engine, while the helicopter is equipped with a mono-turbine, this concept offering the best weight / power / reliability ratio in this power range.

For the UAV, the recommended cruise speed for the mission is 65 kts at an altitude of 3000 ft. The speed considered for the calculation of CO2 emissions is 65 kts for the UAV and the minimum consumption speed for the other aircraft.

The energy necessary to only transport the payload is approximately 0,3 MJ/kg[3*].

[3*] _Energy needed ≈ energy lost theoretically for a gliding flight._
With a glide ratio of about 10 (passenger plane, best glide ratio compared to other solutions) over a distance of 300km :
Energy needed ≈ 400 kg * 9.81 m/s2 * 30 km ≈ 120 MJ ➔ 0.3 MJ/kg

Type	Engine / Fuel	Power max	Empty weight	CO2 for the mission[1]	Energy consumed per kg of payload for the mission	GHG Carbon Footprint - Production & End of Life[2]	Carbon footprint mission + production & end of life[3]
Soft wing drone	Pistons / AVGAS	100 kW	325 kg	129 kg	4 MJ/kg	10,8 t	132 kg
Light helicopter	Mono turbine / Jet A	377 kW	989 kg	615 kg	13 MJ/kg	26,7 t	628 kg
Light airplane	Pistons / AVGAS	310 kW	1031 kg	189 kg	5 MJ/kg	27,9 t	192 kg

1. OPERATIONS
Emissions in kg of CO2 equivalent, calculated over 300km at the optimal fuel economy speed for the existing vectors (112kt for light helicopter; 164kt for cargo aircraft) and with the following references:
- *1 kg of AVGAS burned = 3.77 kg eq-CO2 (direct and indirect emissions, calculated in the European perimeter)*
- *1 kg of Jet A = 3.83 kg eq-CO2 (direct and indirect emissions, calculated in the European perimeter)*

2. PRODUCTION & END OF LIFE OF THE AIRCRAFT
Assumption of 27 kg eq-CO2 / kg of aircraft produced for a thermal aircraft (EcoInvent V2.2). Emissions related to waste treatment are emissions are negligible compared to those related to production (0.015 kg CO2 eq / kg of aircraft, EcoInvent V2.2)

3. Production & end of life carbon balance integrated in the mission carbon balance by taking the lifespan of the aircraft. 10,000 hours life span for the soft wing UAV (with canvas change every 1,000 hours), 3,000 hours for the light helicopter for the light helicopter and 10 000 hours for the light aircraft.

The CO2 emissions of the helicopter during the mission are 4.7 times higher than those of the drone, while those related to construction and dismantling are 2.5 times higher.

The aircraft's CO2 emissions during the mission are 1.46 times higher than those of the UAV, emissions during construction and dismantling are 2.6 times higher.

The non-recurring part of the emissions in the calculation of the total emissions of the mission is 2% for the drone, 2% for the light helicopter and 1% for the light airplane.

Total emissions for the helicopter are 4.7 times higher than for the drone. The total emissions of the airplane are 1.4 times higher than those of the drone.

In this example, the difference in carbon footprint in favor of the UAV is due to the fact that the design and choice of the aeropropulsion system of the UAV is optimized for the mission, while the helicopter and the airplane are oversized for the mission (cargo volume, maximum internal load, cruising speed, etc.), in addition to the fact that they must have a cockpit to accommodate the pilot.

The mission carbon footprint ratios decrease slightly when the construction and operation footprints are included.

It is important to note that the airplane needs an airfield to take off and land, which is not the case for the other two aircrafts.

5- Summary of carbon footprint comparisons for the cases studied

The table below summarizes the differences in carbon footprint of manned aircraft compared to UAVs, on the different missions studied with the corresponding payloads.

Mission (Chargeable payload)	Aéronef piloté vs drone de référence	Ratio of CO2 balances during the mission	Production & End-of-Life CO2 balance ratio	Mission + production & end-of-life balance ratio
Mission n°1 (3 kg)	Airplane (*)	**205**	**20**	**84**
Mission n°1bis (3 kg)	Helicopter	**3402**	**81**	**1363**
Mission n°2 (20 kg)	Helicopter	**4,3**	**3,5**	**4**
Mission n°3 (150 kg)	Helicopter	**1,3**	**1,7**	**1,3**
Mission n°4 (400 kg)	Helicopter	**4,7**	**2,5**	**4,7**
	Airplane (*)	**1,5**	**2,6**	**1,4**

(*) Need an airfield to take off and land

6- Additional analysis of logistics missions

In the previous comparison, the logistics UAVs studied are prototypes whose cargo volume and payload prefigure those of the logistics UAVs expected to appear on the market in the next decade.

In order for the study to be truly representative of real logistics operations, it is useful to compare their carbon footprint with that of piloted aircraft with a greater carrying capacity, which would make only one rotation instead of several for drones whose carrying capacity is limited in volume and mass.

To this end, the two logistics drone concepts mentioned in this paper:

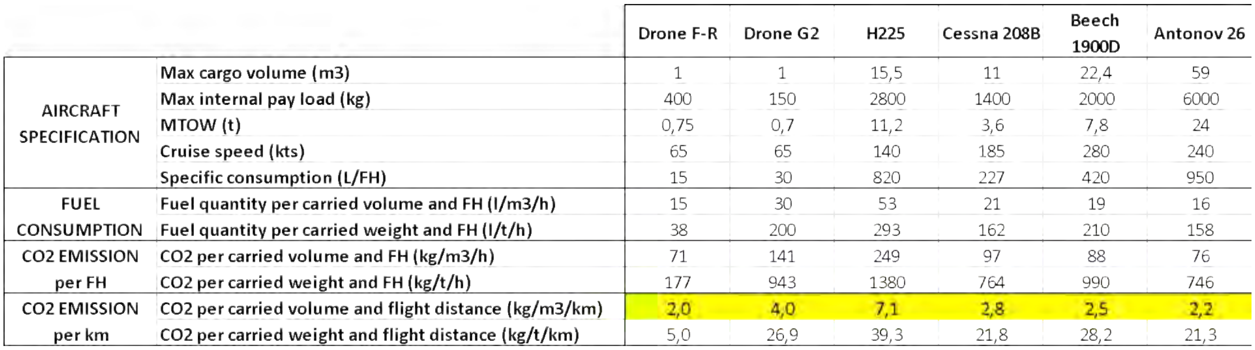
- A drone based on the Cabri G2 helicopter with a carrying capacity of 1 m3 and 150 kg
- A drone with flexible wings based on Flying-Robots FR102 with a carrying capacity of 1 m3 and 400 kg

are compared with four aircrafts commonly used for medium-distance logistics transport:

- A heavy helicopter of the Super Puma family (H225)
- A Cessna 208B Caravan single turboprop cargo aircraft
- One Beechcraft B1900D twin-turbo prop cargo aircraft
- A twin-turbo prop cargo plane Antonov 26

			
H225	208B Caravan	B1900D	An-26

In the table below, the quantities of CO2 emitted during the flight are reduced to the unit of volume or mass transported and the unit of distance traveled.



		Drone F-R	Drone G2	H225	Cessna 208B	Beech 1900D	Antonov 26
AIRCRAFT SPECIFICATION	Max cargo volume (m3)	1	1	15,5	11	22,4	59
	Max internal pay load (kg)	400	150	2800	1400	2000	6000
	MTOW (t)	0,75	0,7	11,2	3,6	7,8	24
	Cruise speed (kts)	65	65	140	185	280	240
	Specific consumption (L/FH)	15	30	820	227	420	950
FUEL CONSUMPTION	Fuel quantity per carried volume and FH (l/m3/h)	15	30	53	21	19	16
	Fuel quantity per carried weight and FH (l/t/h)	38	200	293	162	210	158
CO2 EMISSION per FH	CO2 per carried volume and FH (kg/m3/h)	71	141	249	97	88	76
	CO2 per carried weight and FH (kg/t/h)	177	943	1380	764	990	746
CO2 EMISSION per km	CO2 per carried volume and flight distance (kg/m3/km)	2,0	4,0	7,1	2,8	2,5	2,2
	CO2 per carried weight and flight distance (kg/t/km)	5,0	26,9	39,3	21,8	28,2	21,3

These indicators make it possible to compare, on the one hand, a piloted airplane or helicopter loaded to its maximum capacity, and on the other hand, a fleet of UAVs with a smaller carrying capacity, but whose cumulative capacity would be equivalent to the aircraft studied.

The comparisons of the amount of CO2 emitted during the mission are more balanced than in the previous study, with the exception of the heavy helicopter which remains penalized.

Compared to an airplane with a full cargo hold, a fleet of drones is more advantageous when serving an unprepared area, while the cargo plane remains competitive when serving an airfield.

If the area to be served is at an acceptable distance from an airfield, the impact of ground delivery to cover the last few kilometers must be included in the carbon balance. This correction will interfere in favor of drones and to the detriment of cargo planes.

Obviously, if the aircraft is not fully loaded, the balance will very quickly shift in favor of the fleet of drones, whose number will have been adjusted as needed.

Summary

While light manned air assets will always be justified for certain specific missions, both theoretical and practical comparisons tend to show that the carbon emission balances would be significantly more favorable if operations were carried out by UAVs with a comparable mission capacity, especially as the payload is low.

The comparison is indisputable for surveillance missions, for which the use of drones is much more advantageous in terms of greenhouse gas emissions than the use of piloted aircraft.

Although more nuanced, the comparison with cargo aircraft or helicopters is also quite favorable to drones for the logistics missions analyzed here. The use of drones in the category studied is clearly more advantageous than that of manned aircraft when it comes to serving an area not directly accessible to cargo aircraft and/or when demand does not allow the aircraft to be loaded to its full capacity.

Our readers are of course invited to enrich the reflection by reacting to this document and by contributing to complete it.