



UNIVERSITAT POLITÈCNICA DE CATALUNYA

BARCELONATECH

Escola Tècnica Superior d'Enginyeries  
Industrial i Aeronàutica de Terrassa

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**Study of a feasible solution for a specific mission with unmanned aerial vehicles(UAV/RPAS)**

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**Aitor Martín Sierra**

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# **Study of a feasible solution for a specific mission with unmanned aerial vehicles(UAV/RPAS)**

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Escola Superior d'Enginyeries Industrial, Aeroespacial i Audiovisual de  
Terrassa

ESEIAAT

**Grau en Enginyeria en Tecnologies Aeroespacials**

Autor: Ferran Lozano Rocabeyera

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**Juny 2016**



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## List of Abbreviations

**AoA:** Angle of attack

**DC:** Direct Current

**EPP:** Expanded Polypropylene

**ICE:** Internal Combustion Engine

**MTOW:** Maximum Take-Off Weight

**UAS:** Unmanned Aerial System

**UAV:** Unmanned Aerial Vehicle



## Nomenclature

$C_L$ : Lift Coefficient

$V$ : speed

$R$ : turn radius

$\dot{\psi}$ : Turn rate

$\phi$ : Bank angle

$L_v$ : Distance between leading edges of wing and elevator

$V_v$ : Tail volume coefficient

$S_v$ : Elevator surface



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## 1. State of the Art of the UAV industry

### 1.1. DJI

DJI is a Chinese UAV manufacturer for aerial photography and videography and it is considered to be one of the leading companies in civilian drone industry. DJI manufactures different type of products as it can be seen in the list below:

- Aerial cameras
- Flying platforms
- Flight controllers for multirotor
- Accessories for helicopters
- Camera gimbals
- Ground stations

#### 1.1.1. Phantom Series

This UAV series consist on quadcopters that are prepared for aerial photography and cinematography. The models that are on sale at this moment will be analysed:



Figure 1: Phantom 3[1]

- Phantom 2

The Phantom 2 is the oldest model on sale. However, the technology involved in the Phantom 2 is quite innovative and the table below summarizes the most notable specifications[2]:

**Table 1: Phantom 2 specifications**

<b>PHANTOM 2 SPECIFICATIONS</b>	
General features	
- Auto Return-to-home & Landing	
- Easy battery replacement	
- Flight time: 25 min	
- Weight: 1 kg	
- Dimensions: 29x29x18 cm	
- Communications distance: 1 km	
- No Fly Zone feature	
- Integrated GPS auto-pilot system	
Aircraft	
- MTOW: 1.3 kg	
- Max. yaw angular velocity: 200°/s	
- Max. tilt angle: 35 °	
- Max. ascent speed: 6 m/s	
- Max. descent speed: 2 m/s	
- Max. flight speed: 15 m/s	
- Operating temperature: -10°C to + 50°C	
Battery	
- 3S LiPo Battery	
- Capacity: 5200 mAh	
- Voltage: 11.1 V	
Price: 399 €	

- New Phantom models

The new phantom family is formed by the Phantom 3 Standard, Phantom 3 Professional & Advanced and Phantom 4. The comparison of this models can be seen in the following table [1]:

**Table 2: New Phantom models**

Phantom 3	Phantom 3 Professional	Phantom 4
General		
<ul style="list-style-type: none"><li>- For beginners and first-time pilots</li><li>- Automatic flight assistant</li><li>- Auto-hover</li><li>- Safe flight limits: definition of space limits</li><li>- Live GPS</li><li>- Status and detection indicators</li></ul>	<ul style="list-style-type: none"><li>- High level of aerial photography</li><li>- GPS-assisted hover</li><li>- Vision positioning system</li><li>- Automatic flight logs</li><li>- Intelligent battery</li><li>- Inertial Measurement Unit</li><li>- Electronic Speed Controllers (ESCs)</li><li>- Return to home feature</li></ul>	<ul style="list-style-type: none"><li>- High level of aerial photography and cinematography</li><li>- Magnesium skeleton</li><li>- High efficiency motors</li><li>- Optical sensor</li><li>- GPS + GLONASS</li><li>- Vision positioning system with ultrasonic sensors</li></ul>
Aircraft		
<ul style="list-style-type: none"><li>- Diagonal size: 350 mm</li><li>- Weight: 1.22 kg</li><li>- Flight time: 25 min</li><li>- Max. Flight Speed: 16 m/s</li></ul>	<ul style="list-style-type: none"><li>- Diagonal size: 350 mm</li><li>- Weight: 1.28 kg</li><li>- Flight time: 26 min</li><li>- Max. flight speed: 16 m/s</li></ul>	<ul style="list-style-type: none"><li>- Diagonal size: 350 mm</li><li>- Weight: 1.38 kg</li><li>- Flight time: 28 min</li><li>- Max. Flight Speed: 20 m/s</li></ul>
Remote Controller		
<ul style="list-style-type: none"><li>- Flight Mode Switch</li><li>- Gimbal Dial</li><li>- Max. transmission distance: 500 m</li></ul>	<ul style="list-style-type: none"><li>- Flight Mode Switch</li><li>- Gimbal Dial</li><li>- Playback button</li><li>- Shutter button</li><li>- Video Recording button</li><li>- Return to home button</li><li>- Max. transmission distance: 3500 m</li></ul>	<ul style="list-style-type: none"><li>- Flight Mode Switch</li><li>- Gimbal Dial</li><li>- Shutter button</li><li>- Video Recording button</li><li>- Return Home button</li><li>- Intelligent Flight Pause button</li><li>- Max. transmission distance: 3500 m</li></ul>
Price		
599 €	1 199 €	1 599 €

### 1.1.2. Inspire series

The Inspire series are UAVs with the same application as the Phantom series. However, the Inspire are much easier to fly and simple to perform. Also the camera that these models include has been improved in respect to the phantom series. The innovative factors that these models present can be seen in the table below.



**Figure 2: Inspire model[3]**

**Table 3: Inspire series specifications [3]**

Inspire 1	Inspire 1 PRO
General features	
<ul style="list-style-type: none"> <li>- Carbon fibre arms that allows a better maneuverability</li> <li>- 360° unobstructed view</li> <li>- Carbon fibre rotor for a better stability and an excellent performance</li> <li>- Curved magnets in the electric motor for increasing efficiency</li> <li>- Improvement in the ESC</li> <li>- Intelligent GLONASS+GPS system that enables higher precision and quicker satellite acquisition</li> </ul>	<ul style="list-style-type: none"> <li>- The same features as Inspire 1</li> <li>- Camera can capture 4K videos</li> </ul>
Aircraft	
<ul style="list-style-type: none"> <li>- Diagonal size: 559 – 581 mm</li> <li>- Weight: 2.935 kg</li> <li>- Flight time: 18 min</li> <li>- Max. speed: 22 m/s</li> </ul>	<ul style="list-style-type: none"> <li>- Diagonal size: 559 mm</li> <li>- MTOW: 3.5 kg</li> <li>- Flight time: 15 min</li> <li>- Max. speed: 18 m/s</li> </ul>
Remote controller	
<ul style="list-style-type: none"> <li>- Frequency: 5.8 GHz &amp; 2.4 GHz</li> <li>- Max. transmission distance: 5 km</li> </ul>	<ul style="list-style-type: none"> <li>- Frequency: 5.8 GHz &amp; 2.4 GHz</li> <li>- Max. transmission distance: 5 km</li> </ul>
Price	
2 299 €	4 399 €

## 1.2. 3D Robotics

3D Robotics is an American company that manufacture UAVs for commercial applications as mapping and aerial photography. The type of UAVs that 3DR produces include fixed-wing drones and quadcopters. However, in November of 2015 the company announced that they will only produce one model of UAV, the SOLO drone.

### 1.2.1. SOLO drone

The main application for this quadcopter is aerial photography and video and it has been developed specially to perform with a GoPro camera. Some specifications can be seen in the following table [4]:



Figure 3: 3DR SOLO drone[4]

Table 4: SOLO specifications[4]

3DR SOLO drone specifications	
MTOW	1.8 kg
Dimensions	25x46x46 cm
Flight time	25 min (without payload) 20 min (with payload)
Range	8 km
Max. speed	89 km/h
Max. ascent and descent speed	10 m/s
Max. payload weight	420 g
Max. Altitude	122 m

Propulsion system	Electric motors 880 kV
Price	817 €

### 1.3. SenseFly

SenseFly is a Swiss company that develops and produces aerial imaging drones for professional applications. The most important drones that this company produces have been analysed.

#### 1.3.1. eBee

This mapping fixed-wing drone can transform aerial photos into orthomosaics and 3D models. There are different models of this drone depending on the applications. For agriculture purposes the company has developed the eBee Ag. It incorporates anti-collision avoidance. The specifications for the general eBee can be seen in the following table.[5]



Figure 4: eBee drone[5]

**Table 5: eBee specifications**

Weight	0.69 kg
Wingspan	96 cm
Material	EPP foam, carbon structure and composite parts
Propulsion	Electric brushless DC motor (160 W)
Battery	11.1 V, 2150 mAh
Max. flight time	50 min
Cruise speeds	40 – 90 km/h
Radio link range	3 km
Price	10 560 € [6]

### 1.3.2. eXom

This sensor-rich quadcopter drone that has different applications such as high-resolution mapping, 3D modelling and inspection. The camera that this model includes can switch between HD and thermal video imagery during the flight and an ultrasonic sensor allows detection in a range of 6 m. Some specifications can be seen below [7]:

**Table 6: eXom specifications**

Dimensions	56x80x17 cm
MTOW	1.8 kg
Flight time	22 min
Propulsion	4 electric brushless motors
Max. climb rate	7 m/s
Max. airspeed	12 m/s
Communication link range	800 m
Price	-

## 1.4. CATUAV

CATUAV is a Spanish private company dedicated to Earth observation and remote sensing services using UAVs. The drones that the company manufactures are not for sale, the client can only contract the service that is done. However, the following models used by the manufacturer have been studied.

**Table 7: CATUAV UAV models[8]**

Model	Type of UAV	Range	Flight time	Payload weight	Cruise speed	Propulsion
<b>Atmos 6</b>	Fixed wing	15 km	60 – 120 min	0.5 kg	45 km/h	Electric
<b>Mineos</b>	Fixed wing	15 km	60 min	0.5 kg	75 km/h	Electric
<b>Argos Electric</b>	Fixed wing	15 km	100 – 200 min	5.88 kg	60 km/h	Electric
<b>Argos</b>	Fixed wing	15 km	14 h	6.250	68 km/h	ICE
<b>Furos</b>	Fixed wing	15 km	6 h	5 kg	70 km/h	ICE
<b>Heli500</b>	Helicopter	4 km	18 min	0.5 kg	35 km/h	Electric

Some of the models have been described with more detail:

### 1.4.1. Atmos 6

The small size of the Atmos 6 and the silent electric motor makes it a perfect drone for surveillance applications. It includes a GPS navigation system and an automatic stabilizer system. In the following table some of the specifications can be seen.[8]



**Figure 5: Atmos 6[8]**

**Table 8: Atmos 6 specifications**

Wingspan	1.80 m
Length	1.29 m
Minimum weight	1.3 kg
MTOW	1.8 kg
Propulsion system	Electric brushless motor
Stall speed	18 km/h
Cruise speed	45 – 50 km/h
Max. speed	80 km/h
Max. flight time	3 h
Range	15 km

#### 1.4.2. Mineos

The Mineos UAV has been designed for video surveillance and remote sensing purposes. It has a GPS navigation system and an automatic stabilizer locator transmitter. Some of the specifications have been summarized in the table below.[8]

Wingspan	1.72 m
Length	1.1 m
Minimum weight	2 kg
MTOW	2.5 kg
Propulsion system	Electric brushless motor
Stall speed	20 km/h
Cruise speed	75 km/h
Max. speed	110 km/h
Max. flight time	1 h
Range	15 km

### 1.4.3. Argos

This model incorporates a landing gear in order to take-off from short runways but also has the possibility of catapult launching. The fuel engine ensures large flight times and high speeds as opposed to the limitations of electric motors.

**Table 9: Argos specifications**

Wingspan	3 m
Length	1.92 m
Height	44.5 cm
Mean aerodynamic chord	28.88 cm
Aspect Ratio	10.42
Airfoil	FRUF02
Minimum weight	5.75 kg
MTOW	12 kg
Fuel tank	3500 cc
Propulsion system	2-stroke engine
Fuel consumption	0.25 L/h
Stall speed	26 km/h
Cruise speed	68 km/h
Max. speed	130 km/h
Max. flight time	14 h
Range	15 km

## 1.5. CARTOUAV

CARTOUAV is a Spanish drone manufacturer. Among their products, there are fixed-wing drones and quadcopters. Some of these UAVs had been analysed.

### 1.5.1. Bramor UAV

The Bramor UAV can be used for many civil applications such as cartography, agriculture or surveillance. Some innovative aspects are the complete autonomous flight from take-off until landing and the small retractable gimbal system equipped. Some specifications can be seen in the following table. [9]



**Figure 6: Bramor UAV [9]**

**Table 10: Bramor UAV specifications**

Weight	3.2 kg
Payload	0.6 kg
Stall speed	30 km/h
Cruise speed	62 km/h
Max. flight speed	104 km/h
Propulsion	Electric
Flight time	120 min
Control range	40 km
Take-off	Catapult
Landing	Parachute
Min. Altitude	70 m
Max. Altitude	2000 m

### 1.5.2. MD4

There are 2 models of these quadcopters, the MD4-200 and MD4-1000. The possible applications are traffic control, inspection, audio-visuals, agriculture among others. The MD4-200 is a better choice when maneuverability and small dimensions are vital. On the other hand, the MD4-1000 it has been designed for work under bad weather conditions and when a large flight time is required. The table below shows the specifications of both models. [10]

**Table 11: MD4 models specification**

Specifications	MD4-200	MD4-1000
<b>Weight (kg)</b>	0.8	4.3
<b>Payload (g)</b>	300	1200
<b>Dimensions between axels (cm)</b>	54	109
<b>Flight time (min)</b>	30	60
<b>Ceiling (m)</b>	1000	1000
<b>Max. height above sea level (m)</b>	4000	4000
<b>Wind resistance (m/s)</b>	5 - 6	10 - 13

## 1.6. Brocktek

Brocktek is an unmanned aerial and ground system manufacturer of the United States. Among the civilian applications that their products have surveillance, agriculture and forest management are the most interesting. Aside from civil applications, the government and defence industry are also a user.

### 1.6.1. Havoc UAS

The Havoc is a long-endurance UAS that can be used for a large range of application such as surveillance, search & rescue, agriculture and infrastructure management.


**Figure 7: Havoc UAS[11]**

The specifications can be seen in the following table:

**Table 12: Havoc UAS specifications[11]**

HAVOC UAS SPECIFICATIONS	
Fuselage	3,2 m
Wingspan	4,9 m
Empty weight	38 kg
Max Payload weight	20 kg
MTOW	79 kg
Endurance	8 - 18 h
Stall speed @Empty weight	52 km/h
Stall speed @MTOW	65 km/h
Launch	Manual or Auto Rolling
Recovery	Manual or Auto Rolling
Altitude	1500 m - 3000 m

### 1.6.2. Spear UAS

The Spear is a lightweight and portable UAS with a tool-less assembly system that allows making modifications or upgrading any component. As well as the Havoc, it can be used for many applications. There are two possible configurations: electric o ICE.


**Figure 8: Spear UAS[12]**

The specifications can be seen in the table below:

**Table 13: Spear UAS specifications[12]**

SPEAR UAS SPECIFICATIONS	
Fuselage	1,9 m
Wingspan	3 or 4,3 m
Empty weight	9,5 kg
Max Payload weight	1 kg (electric) or 4,5 kg (ICE)
MTOW	17 kg
Endurance	1 h (Electric) or 2,8 h (ICE)
Stall speed @Empty weight	36 km/h
Stall speed @MTOW	46 km/h
Launch	Manual
Recovery	Manual or Belly Skid
Altitude	3000 m

## 1.7. Latitude

This American manufacturer has developed the Hybrid Quadrotor Technology that consists on combining the maneuverability and VTOL of a quadrotor with the efficiency and long endurance of a fixed wing drone.

The HQ 60 incorporates this technology in order to provide a long endurance UAS. The dual gas/electric propulsion system allows flying with the correct power source in every moment of the mission.


**Figure 9: Hybrid UAV HQ 60[13]**



Although the specifications are not provided in the official website of the manufacturer, some basic features can be seen in the table below.

**Table 14: HQ -60 basic specifications[14]**

Empty weight	11.3 kg
Endurance	12 – 24 h
Payload capability	3.6 – 5.4 kg
Propulsion system	4 propellers driven by an individual electric motor and in cruising altitude the UAV is powered by a 370 W hp 4-stroke gas engine
Cruising speed	74 km/h

## 1.8. Zala Aero

Zala Aero is a Russian manufacturer specialised on UAVs that has supplied several UAS to the Russian government. This company cooperates with Gazprom Space Systems to allow real time video using satellite communication channels in digital format to different receiving stations. The main applications of their products are monitoring and surveillance.

### 1.8.1. Zala 421-08

Zala 421-08 is a lightweight UAV easily to transport and that can be used for surveillance applications. It can be controlled in both autonomous and semi-autonomous modes. The specifications are showed in the following table [15]:

**Table 15: Zala 421-08 specifications[15]**

ZALA 421-08 SPECIFICATIONS	
Payload	video & infrared camera
Max Range	15 km
Endurance	100 min
Altitude	4000 m
Wingspan	81 cm
Length	42,5 cm
Weight	2,1 kg
Speed	65-130 km/h
Engine	electric



Launch	Hand launched
Landing	parachute
Navigation GPS	GPS/GLONASS

### 1.8.2. Zala 421 -04M

This UAV is an aerial digital camera that can change into different modes such as gyro-stabilised video or infrared camera. The specifications of this UAV have been summarized in the following table.

Table 16: Zala 421-04M specifications[15]

ZALA 421-04M SPECIFICATIONS	
Payload	1 kg (video and infrared cameras)
Max Range	40 km
Endurance	120 min
Altitude	3600 m
Wingspan	1,6 m
Length	0,62 m
Weight	4,2 kg
Speed	65-120 km/h
Engine	electric
Launch	catapult
Landing	parachute
Navigation GPS	GPS/GLONASS

### 1.8.3. Zala 421-16

The main application that this drone has is monitoring as well as search and detection of objects. Is capable of real-time video, infrared data acquisition and transfer, position and visual targets detection, data storage and procession. The specification for the Zala 421-16 have been tabulated:

**Table 17: Zala 421-16 specifications[15]**

ZALA 421-16 SPECIFICATIONS	
Endurance	7 h
Speed	150 km/h
Range	50 km
Engine	internal combustion engine
Wingspan	1,62 m
MTOW	18 kg
Take-off and landing area	50*50 m
Launch	Catapult
Payload weight	3 kg

## 1.9. Insitu

Is an American company that builds UAV and in 2008 was bought by Boeing. Their products have civilian, commercial and defence applications. However, the main civil applications are inspection, agriculture, Oil and gas operations, border patrol and wildfire management.

### 1.9.1. Integrator

This multi-mission UAV can be suited for a large range of applications and has a great payload capability due to the 6 spaces dedicated only for carrying specific mission objects.


**Figure 10: Insitu Integrator UAV[16]**

The specification table can be seen below:

**Table 18: Insitu Integrator specifications[17]**

Integrator SPECIFICATIONS	
Length	2,5 m
Wingspan	4,9 m
Empty weight	36,28 kg
MTOW	61,2 kg
Max Payload Weight	18 kg
Endurance	24+ hours
Ceiling	5,944 m
Max. Horizontal speed	46,3 m/s
Cruise speed	28,3 m/s
Engine	EFI
On-board power	350 W for payload
On-board connectivity	Ethernet

## 1.10. Aeraccess

Aeraccess is a French manufacturer dedicated to design drone based solutions focused on security and defense applications.

### 1.10.1. GOSHAWK W200

The GOSHAWK is a high endurance fixed wing drone that has been designed for covering large surface areas. The main application of this model are surveillance and reconnaissance missions. The strong points are the ultra-performant sensors that enables detecting objects from large distances, easy assembly system and security systems that provides reliability.



**Figure 11: GOSHAWK W200 UAV[18]**

Some basic specifications can be seen in the following table:

**Table 19: GOSHAWK W200 UAV specifications[18]**

Length	1,5 m
Wingspan	2 m
MTOW	6 kg
Flight cruise speed	90 km/h
Max Payload Weight	1 kg
Endurance	90 to 120 min
Ceiling	1000 m
Launcher	Catapult
Landing	Parachute or Soft landing
Engine	Electric motor
On-board computer	Highly stabilised flights Waypoints flight control Secured datalink Live Data Transmission Failure Management
Payload	Visible and IR sensors 360° view sensor control Integrated Retractable turret system
Control	Classic Radio Control Tablet control GCS control

## 1.11. Wake Engineering

Wake Engineering is a Spanish company that designs and produces UAV. The principal drone that they manufacture has been described.

### 1.11.1. Fulmar

Fulmar is an easiness fixed wing UAV with a low maintenance cost and with high technical capabilities. The main applications for this drone are search & rescue missions, surveillance, defence among others. The strengths that this model has are completely autonomous operation, great operation range, automatic detection system and multi-tracking.



Figure 12: Fulmar UAV[19]

The following table summarises some basic specifications:

Table 20: Fulmar UAV specifications[20]

Length	1,2 m
Wingspan	3 m
Height	0,5 m
Flight cruise speed	100 km/h
MTOW	20 kg
Endurance	6 - 12 h
Ceiling	4000 m
Max. Payload Weight	8 kg
Operation Range	800 km
Video Camera Range	70 - 90 km
Propulsion system	Gasoline Engine
Launcher	Catapult

## 1.12. UAV Factory

UAV Factory is one of the world's leading UAS manufacturers. Among their products, there are UAVs, catapults systems, control stations, fuel injected engines, power generators etc. The main fixed wing drones designed by the company had been analysed.

### 1.12.1. Penguin C UAS

This UAV model is prepared for surveillance applications thanks to the large endurance and the capability to fly during day and night. Another important feature to take into account is the 100 km range of digital link for video and control. Although it needs of a catapult for take-off, it is easily portable.



**Figure 13: Penguin C UAV[21]**

The specification table can be seen in the following table.

**Table 21: Penguin C specifications[21]**

Penguin C	
Wingspan	3,3 m
MTOW	22,5 kg
Endurance	20 h
Range	100 km
Cruise speed	19 - 22 m/s
Max level speed	32 m/s
Ceiling	4500 m
Take-off	Pneumatic Catapult, fully autonomous
MTOW altitude	3000 m
Recovery	Parachute recovery, airbag
Propulsion system	Fuel injected engine, 28 cc

Generator system	100 W on-board generator system
Payload type	Day/night gyro stabilized

### 1.12.2. Penguin B UAS

The Penguin B is very similar to the Penguin C model but it incorporates a universal payload mount that is easily removed in order to use different type of payloads. The specifications can be seen in the following table:

Table 22: Penguin C specifications[22]

Penguin C	
MTOW	21,5 kg
Empty Weight	10 kg
Wingspan	3,3 m
Length	2,27 m
Wing area	0,79 m <sup>2</sup>
Powerplant	2,5 hp
Max payload	10 kg
Take-off	Catapult, Runway or car top launch
Endurance	20+ hours
Cruise speed	22 m/s
Stall speed	13 m/s
Max level speed	36 m/s
Take-off run	30 m
CL max	1,3
CL max with 45° flap deflection	1,7

### 1.12.3. Penguin BE Electric Platform

This Penguin model is also very similar to Penguin B but the main difference is the electric propulsion instead of the fuel injected engine. According to the manufacturer, is the best option for short duration missions.

The specifications had been summarised in the table below:

**Table 23: Penguin BE specifications [23]**

Penguin BE	
MTOW	21,5 kg
Empty Weight	14,9 kg
Wingspan	3,3 m
Length	2,27 m
Wing area	0,79 m <sup>2</sup>
Propulsion type	Geared brushless motor
Propulsion power	2700 W
Battery type	Lithium Polymer
Battery Capacity	640 Wh
On-board voltage	6 V, 12 V
On-board continuous power	100 W
Max. Payload	6,6 kg
Take-off method	Catapult, Runway or car top launch
Endurance	110 min with 2,8 kg payload
Cruise speed	22 m/s
Stall speed	13 m/s
Max speed	36 m/s
Take-off run	30 m
CL max	1,3
CL max (45 flap deflection)	1,7
Ceiling	6000 m

### 1.13. Draganfly

Draganfly is a Canadian company that has more than 18 years of experience in the UAV industry. The main drones that they offer are multicopters. However, an interesting fixed wing UAV will be available in 2016. Some of the products they offer have been analysed.

#### 1.13.1. Tango UAV

This fixed wing UAV presents a tandem wing configuration in order to perform a great stability. It is fully autonomous and presents an assembly system that facilitates the

transportation. The main applications are aerial photography and video. The specifications can be seen in the table below:



Figure 14: Tango UAV[24]

Table 24: Tango UAV specifications[25]

Tango UAV	
Wingspan	150 cm
Length	120 cm
Wing Area	0,5625 m^2
Empty weight	2,8 kg
Payload capability	1,14 kg
MTOW	3,94 kg
Cruise speed	50 - 60 km/h
Maximum speed	95 km/h
Stall speed	35 km/h
Launch type	Catapult
Maximum altitude	640 m
Endurance	50 min

### 1.13.2. Draganflyer Guardian

The draganflyer Guardian is a quadcopter that can be used for industrial inspection, agriculture, mapping, public safety or aerial photography and videography.



**Figure 15: Draganflyer guardian UAV [26]**

The basic specifications of the Draganflyer guardian can be seen in the following table.

**Table 25: Draganflyer Guardian specifications [26]**

Draganflyer Guardian	
Width	59.5 cm
Length	59.5 cm
Top diameter	72.5 cm
Height	25.5 cm
MTOW	1.4 kg
Payload capability	420 g
Max. climb and descent rate	2 m/s
Propulsion	Electric motor
Price	6215 €

## 1.14. Parrot

Parrot is a French drone manufacturer that is specialized in wireless communications. Apart from UAVs, they offer controllers and First Person View glasses.

### 1.14.1. Bebop

The main application of this multirotor drone is aerial photography and videography. One peculiarity of this model is that the camera is implemented inside the fuselage. The most important specifications have been tabulated:



Figure 16: Bebop drone[27]

Table 26: Bebop specifications [27]

Bebop	
Dimensions	33x38x3.6 cm
Weight	0.42 kg
Speed	13 m/s
Flight time	22 min
Propulsion	4 brushless motors
Link range	250 m
GNSS	Yes
Price	399 €



## 1.15. Lehmann Aviation

Lehmann Aviation is a French drone manufacturer that designs UAV for amateur and civilian applications. The most characteristics products have been studied.

### 1.15.1. L-A Series

The L-A series drones have fixed-wing configuration. The principal applications are aerial photography, mapping and agriculture. The basic specifications have been tabulated.

Table 27: L-A series specifications[28]

L-A series	
Wingspan	92 cm
Length	45 cm
Weight	950 g
Payload capability	200 g
MTOW	1.15 kg
Cruise speed	20 - 80 km/h
Maximum speed	95 km/h
Launch type	Hand launch
Maximum altitude	500 m
Propulsion	Electric motor
Endurance	45 min
Price	2 890 € (mapping drone) 8 990 € (precision agriculture model)

### 1.15.2. L-M Series

The L-M series are UAV platforms designed for short range surveillance. The most expensive model is the platform that incorporates a thermal camera. The specifications for this model have been summarized in the following table:

**Table 28: L-M series specifications[29]**

LP960	
Wingspan	92 cm
Length	45 cm
Payload capability	350 g
MTOW	1.25 kg
Cruise speed	20 - 80 km/h
Maximum speed	95 km/h
Launch type	Hand launch
Maximum altitude	500 m
Propulsion	Electric motor
Endurance	45 min
Range	5 km
Price	6 990 €

## 2. Matlab codes

### 2.1. Estimation take-off distance

```
%INPUTS

v=24; %m/s

m=20; %kg

d_TO=linspace(0,150,16);

n=length(d_TO);

F=zeros(n);

P=zeros(n);

for i=1:n

    F(i)=(m*v*v) / (2*d_TO(i));

    P(i)=F(i)*v;

end

figure(1)

plot(d_TO,F);

xlabel('Take-off distance (m)');

ylabel('Thrust (N)');

title('Take-off distance vs thrust');


figure(2)

plot(d_TO,P)

xlabel('Take-off distance (m)');

ylabel('Power (W)');

title('Take-off distance vs Output Power');
```



## 2.2. Constraint analysis

```
clear all
close all
%Constraint analysis
%Inputs
nau=0.7;
ro=1.21; %kg/m^3
V=14; %m/s
Cd0=0.018;
K=0.014;
n=3;
d_TO=30;%m
CL_max=1.3;
V_stall=13; %m/s
g=9.8;%m/s^2
ro_SL=1.225; %kg/m^3
%Constraints equations
W_S=linspace(0,200,11);
n=length(W_S);
P_W_load=zeros(1,n);
P_W_endurance=zeros(1,n);
P_W_cruise=zeros(1,n);
P_W_TO=zeros(1,n);
Pto_Pcr=1;
W_Wto=0.95;
A=17.5;
e=1.3;
for i=1:n
    %Maximum load
```

```

P_W_load(i)=(1/550*nau)*(0.5*ro*V^3*Cd0*(1/W_S(i))+2*K*(n^2/ro*V)*W_S(
i));
%Endurance

P_W_endurance(i)=(4/550*nau)*Cd0^0.25*(K/3)^0.75*((2/ro)*W_S(i))^0.5;
%Cruise

q=0.5*ro*V^2;

P_W_cruise(i)=Pto_Pcr*ro*V/(W_S(i)*nau)*(Cd0+((W_S(i)*W_Wto)^2)/(q^2*p
i())*A*e));
%Take-off distance

P_W_TO(i)=(2.44/550*nau)*(1/g*d_TO)*((1/ro_SL*CL_max)*W_S(i))^1.5;

end

%Stall condition

for i=1:n

W_S_stall(i)=0.5*ro*CL_max*V_stall^2;
end

P_W_stall=linspace(0,50,n);

hold on
grid on

plot(W_S,P_W_TO,'g');
plot(W_S,P_W_load,'r');
plot(W_S,P_W_stall,'m');
plot(W_S,P_W_cruise,'b');
plot(W_S,P_W_endurance,'k');

xlabel('W/S (N/m^2)');
ylabel('P/W (W/N)');

```



```
legend('Take      off      requirements','Load      requirements','Stall  
requirements','Cruise                      requirements','Endurance  
requirements','Location','NorthEastOutside');
```

### 2.3. Calculation of the take-off distance

```
%TAKE-OFF DISTANCE CALCULATION

%Inputs

V_stall = 20.636; %m/s
W = 20*9.81; %N
V_TO = 1.3*V_stall; %m/s
mu = 0.04;
S = 0.525; %m^2
g = 9.81; %m/s^2
rho = 1.225; %kg/m^3
n_p = 0.7;
P_engine = 4000; %W

% Maximum efficiency lift and drag coefficients
C_L = 0.653;
C_D = 0.018;
E = C_L/C_D;

%Ground Roll Segment

V_average= 0.7*V_TO;
P_avaible= n_p*P_engine;
T = P_avaible/V_average;
K_T = T/W - mu;
K_A = (rho/ (2* (W/S) )) * ( (mu*C_L) -C_D) ;
V_i = 0;
V_f = V_TO;
```



```
S_G      = (1 / (2*g*K_A)) * log((K_T + K_A*V_f) / (K_T + K_A*V_i)); %m

S_R      = V_TO; %m

S_Roll   = S_G + S_R;

%Transition

R        = 0.205 * (V_stall)^2;
sin_gamma = (T/W) - (1/E);
S_T      = R * sin_gamma;

%Take-off distance

d_TO     = S_G + S_R + S_T;
```

## 2.4. Calculation of landing distance

```
%LANDING DISTANCE CALCULATION

%Inputs

V_stall = 20.636; %m/s
W       = 20 * 9.81; %N
W_land  = 0.85 * W; %N
V_a     = 1.3 * V_stall; %m/s
V_f     = 1.23 * V_stall; %m/s
V_TD   = 1.15 * V_stall; %m/s
mu     = 0.5;
S       = 0.525; %m^2
g       = 9.81; %m/s^2
rho    = 1.225; %kg/m^3
n_p    = 0.7;
P_engine = 4000; %W

% Maximum efficiency lift and drag coefficients
```



```
C_L      = 0.653;
```

```
C_D      = 0.018;
```

```
E       = C_L/C_D;
```

#### %Approach

```
gamma    = 3*(pi/180); %rad
```

```
R        = (V_f)^2/(g*0.2);
```

```
h_obst   = 15; %m
```

```
h_f      = R*(1-cos(gamma)); %m
```

```
S_a      = (h_obst - h_f) / (tan(gamma));
```

#### %Flare

```
S_f      = R*sin(gamma);
```

#### %Ground roll

```
S_FR     = V_TD;
```

```
T        = 0;
```

```
K_T      = T/W - mu;
```

```
K_A      = (rho/(2*(W/S))) * ((mu*C_L) - C_D);
```

```
V_i      = V_TD;
```

```
V_f      = 0;
```

```
S_B      = (1/(2*g*K_A)) * log((K_T + K_A*V_f) / (K_T + K_A*V_i)); %m
```

```
S_Roll   = S_B + S_FR;
```

```
d_L      = S_Roll + S_f + S_a;
```

### 3. Engine market research

Lightweight engines with such a great power are difficult to find, however the following engines manufacturers have been found:

- O.S. Engines

**Table 29: Different O.S Engines models[30]**

Engine	Cylinders	Capacity (cc)	Weight (kg)	Output Power (kW)	Power-to weight ratio (kW/kg)
FS-70	1	11.45	0.502	0.894 at 11000 rpm	1.781
FS-91 S II	1	15	0.649	1.193 at 11000 rpm	1.838
FS-120S III	1	20	0.921	1.56 at 12000 rpm	1.694
FT-160	2	26.5	1.1	1.49 at 11000 rpm	1.354
FS-200U	1	32.4	0.83	2.16 at 9000 rpm	2.605
FT-300	2	49	1.828	3.0 at 7000 rpm	1.641
FF-300 radial	5	49.7	2.673	3.0 at 8000 rpm	1.122
FF-320	4	53.2	2.19	3.06 at 8000 rpm	1.37

- SAITO engines

**Table 30: Saito engine models[30]**

Engine	Capacity (cc)	Weight (kg)	Output Power (kW)	Power-to weight ratio (kW/kg)	Range of rpm
FA-45S	7.5	0.440	0.522	1.186	2000 – 12000
FA-50	8.20	0.435	0.634	1.457	2000 – 12000
FA-56	9.20	0.410	0.671	1.637	2000 – 12000

FA-56F	9.20	0.410	0.671	1.637	2000 – 12000
FA-62a	10.24	0.469	0.746	1.590	2000 – 12000
FA-65	10.60	0.550	0.708	1.288	2000 – 12000
FA-72	11.80	0.470	0.895	1.904	2000 – 12000
FA-80	13.10	0.540	0.969	1.795	2000 – 12000
FA-82a	13.80	0.453	1.119	2.469	2000 – 12000
FA-91 S	15	0.555	1.193	2.150	2000 – 11000
FA-100	17.10	0.551	1.342	2.436	2000 – 11000
FA-120 S	20	0.9	1.641	1.823	1900 – 10500
FA-152a	20.52	0.7	1.641	2.344	1800 – 10500

- RCV Engines

Table 31: RCV engine models[31]

	Single Cylinder	Twin Cylinder
Type	Rotatory valve, spark ignition, 4-stroke	
Cooling	Air cooling	
Lubrication	Oil	
Heavy Fuel Starting	Cold start assisted	
Capacity	35 cc	70 cc
Speed range	2000 – 10 000 rpm	2000 – 10 000 rpm
Power (JP8)	2 kW at 8500 rpm	4 kW at 8500 rpm
Fuel Consumption (JP8)	350 g/kW h	330 g/kW h
Weight (including fuel system, ignition, ECU and exhaust)	1.9	2.7
TBO – Fixed Wing	300 h	
Capacity range	25 to 35 cc	50 to 70 cc

## 4. Study of the tail volume coefficient

The results for the study of the tail volume coefficient can be seen below. The objective of the study is to select the combination of chords that give a reasonable value for the tail volume coefficient.

**Table 32: Study of the tail volume coefficient for a  $L_v$  of 1.3 m**

$L_v = 1.3 \text{ m}$			
$C_{tip} (\text{m})$	$C_{root} (\text{m})$	$S_v (\text{m}^2)$	$V_v$
0.23	0.46	0.138	0.11
0.2	0.4	0.12	0.099
0.15	0.4	0.11	0.091
0.1	0.4	0.1	0.083
0.2	0.35	0.11	0.091
0.15	0.35	0.1	0.083
0.1	0.35	0.09	0.074
0.2	0.3	0.1	0.083
0.15	0.3	0.09	0.074
0.1	0.3	0.08	0.066
0.2	0.25	0.09	0.074
<b>0.15</b>	<b>0.25</b>	<b>0.08</b>	<b>0.066</b>
<b>0.1</b>	<b>0.25</b>	<b>0.07</b>	<b>0.058</b>

**Table 33: Study of the tail volume coefficient for a  $L_v$  of 1.4 m**

$L_v = 1.4 \text{ m}$			
$C_{tip} (\text{m})$	$C_{root} (\text{m})$	$S_v (\text{m}^2)$	$V_v$
0.23	0.46	0.138	0.123
0.2	0.4	0.12	0.107
0.15	0.4	0.11	0.098
0.1	0.4	0.1	0.089
0.2	0.35	0.11	0.098

0.15	0.35	0.1	0.089
0.1	0.35	0.09	0.080
0.2	0.3	0.1	0.089
0.15	0.3	0.09	0.080
0.1	0.3	0.08	0.071
0.2	0.25	0.09	0.080
0.15	0.25	0.08	0.071
<b>0.1</b>	<b>0.25</b>	<b>0.07</b>	<b>0.062</b>

**Table 34: Study of the tail volume coefficient for a  $L_v$  of 1.3 m**

<b><math>L_v = 1.5 \text{ m}</math></b>			
<b><math>C_{tip} (\text{m})</math></b>	<b><math>C_{root} (\text{m})</math></b>	<b><math>S_v (\text{m}^2)</math></b>	<b><math>V_v</math></b>
0.23	0.46	0.138	0.131
0.2	0.4	0.12	0.114
0.15	0.4	0.11	0.105
0.1	0.4	0.1	0.095
0.2	0.35	0.11	0.105
0.15	0.35	0.1	0.095
0.1	0.35	0.09	0.086
0.2	0.3	0.1	0.095
0.15	0.3	0.09	0.086
0.1	0.3	0.08	0.076
0.2	0.25	0.09	0.086
0.15	0.25	0.08	0.076
<b>0.1</b>	<b>0.25</b>	<b>0.07</b>	<b>0.067</b>

## 5. Turning analysis

The results of the turn phase analysis have been tabulated.

Table 35: Turn rate study for a bank angle of 45°

$\phi = 45^\circ$			
AoA (°)	V (m/s)	$\dot{\phi}$ (°/s)	R (m)
0	49.41	11.38	248.86
0.5	44.53	12.62	202.13
1	40.86	13.76	170.19
1.5	37.98	14.80	147.04
2	35.63	15.78	129.41
2.5	33.67	16.69	115.56
3	32.01	17.56	104.45
3.5	30.57	18.39	95.26
4	29.31	19.18	87.57
4.5	28.2	19.93	81.06
5	27.21	20.66	75.47
5.5	26.32	21.36	70.62
6	25.51	22.03	66.34
6.5	24.78	22.68	62.59
7	24.11	23.31	59.26
7.5	23.49	23.93	56.25
8	22.92	24.52	53.55
8.5	22.39	25.10	51.10
9	21.89	25.68	48.85
9.5	21.43	26.23	46.81
10	21	26.77	44.95

10.5	20.6	27.29	43.26
------	------	-------	-------

Table 36: Turn rate study for a bank angle of 60°

$\phi = 60^\circ$			
AoA (°)	V (m/s)	$\dot{\phi}$ (°/s)	R (m)
0	49.41	19.70	143.68
0.5	44.53	21.86	202.13
1	40.86	23.83	170.19
1.5	37.98	25.63	147.04
2	35.63	27.32	129.41
2.5	33.67	28.91	115.56
3	32.01	30.41	104.45
3.5	30.57	31.85	95.26
4	29.31	33.22	87.57
4.5	28.2	34.52	81.06
5	27.21	35.78	75.47
5.5	26.32	36.99	70.62
6	25.51	38.16	66.34
6.5	24.78	39.29	62.59
7	24.11	40.38	59.26
7.5	23.49	41.44	56.25
8	22.92	42.48	53.55
8.5	22.39	43.48	51.10
9	21.89	44.47	48.85
9.5	21.43	45.43	46.81
10	21	46.36	44.95
10.5	20.6	47.26	43.26

Table 37: Turn rate study for a bank angle of 15°

$\phi = 15^\circ$			
AoA (°)	V (m/s)	$\dot{\phi}$ (°/s)	R (m)
0	49.41	3.05	928.77
0.5	44.53	3.38	754.37
1	40.86	3.69	635.15
1.5	37.98	3.97	548.77
2	35.63	4.23	482.96
2.5	33.67	4.47	431.29
3	32.01	4.70	389.81
3.5	30.57	4.93	355.52
4	29.31	5.14	326.82
4.5	28.2	5.34	302.54
5	27.21	5.53	281.67
5.5	26.32	5.72	263.54
6	25.51	5.90	247.57
6.5	24.78	6.08	233.60
7	24.11	6.25	221.14
7.5	23.49	6.41	209.92
8	22.92	6.57	199.85
8.5	22.39	6.73	190.72
9	21.89	6.88	182.29
9.5	21.43	7.03	174.71
10	21	7.17	167.77
10.5	20.6	7.31	161.44

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