IS TO BE A MICRODRONE

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Keywords: *UAV, Tricopter, Surveillance Drone, Tiltrotor, VTOL*

Abstract

Microdrone is not just a compact aircraft, but also an innovative, versatile platform that can be widely used for the quick recognition mission. It has the ability to transform from high performance aircraft to rotorcraft that hovers above the object of interest. The paper begins with the survey of the unmanned platforms available on the market and discussion of their pros and cons. Then there is the description of the chosen configuration - tricopter and prototype test flights results. On this basis, the aircraft conceptual design is made along with its performance estimation. Exemplary profile of the mission is also included.

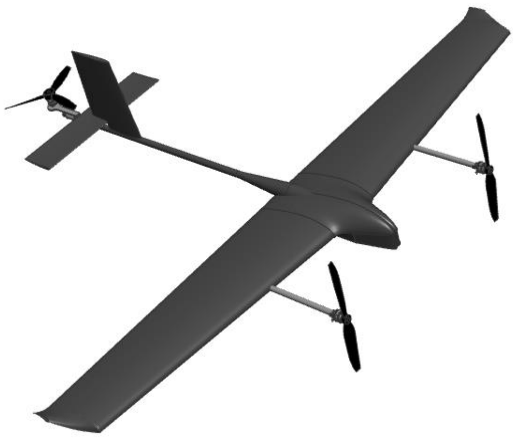

Fig. 1. MICRODRONE

1 MICRODRONE Introduction

Unmanned Aerial Vehicles are used more and more in today's world. They have many advantages over the manned ones. They are cheaper, both in production and operations, they allow keep pilots from danger, help to help others in cases where otherwise the help would not be possible. They are already or soon will be widely used by mountain search and rescue groups, fire brigades, police, military, film industry, airports surveillance, security companies, roads, pipelines and power lines inspections or even intelligent agriculture.

And so can be the MICRODRONE – developement of our SAE Aero Design construction - SKYLARK. (The winner of 2015 and 2016 international students contest - radio controlled 1 meter wingspan construction, ready to fly in approximately 50 seconds, lifting nine times its own weight). This extraordinary airplane gave us the idea and the concept of the kind of UAV we want and can create.

There are a lot of UAVs already on the market. Some can hover, others fly, some can do both. They are smaller and bigger, more and less complicated in use. So what would make our aircraft competitory? After some research we decided that it would be the small and compact one, able to fly for a long time on a long distance, hover in order to observe, vertically start and land if needed. So the key areas of the developement we need to make are: „ready to fly" time, its compactness, flight duration, hovering, take-off and landing in various modes. More specifically:

Table 1. Design Objectives

Type of carrying case	max. backpack dimensions: 700x450x250
Time of assemblance	~ 5 minutes
No. of people handling the assemblance	2
Equipment	• onboard, self-stabilized classic or

	thermographic camera • autopilot • high capacity battery
Flight duration	3 h
Take-off and landing	hand launching/vertical take-off or landing

2 Configuration Selection

There are several configurations of aircraft that enable vertical take-off and landing:

- Standard multirotor platform
- Tailsitter flying wing aircraft
- Tiltrotor monoplane aircraft
- Standard monoplane VTOL
- Tiltwing aircraft

2.1 Standard multirotor platform

Fig. 2. Multirotor platform [1]

Typical multirotor platforms are commonly used in many applications nowadays, from personal video capturing (DJI Phantom [10]) to precision agriculture or technical inspections of radio towers and other objects that are difficult to access (LM Indago UAS [11]).

Pros:

- Easy to build
- Well-developed electronic systems available on the market (autopilots etc.)
- Developing a compact size platform easily achievable
- Stable in flight
- Insensitive to weather conditions

Cons:

- Short flight time due to high demand on power during hovering (1 hour max. flight time of an empty aircraft, 45 min max. flight time with equipment necessary to fulfill the mission)
- Low cruising speed (36m/s)
- Low service ceiling (3500m)

2.2 Tailsitter flying wing aircraft

Fig. 3. Tailsitter platform [2]

Tailsitter VTOLs can occur in many propulsion variants. The most popular are duorotors with two engines mounted on the leading edge or quadrotor with engines mounted under and above the wings.

Pros:

- Compact size thanks to lack of a long fuselage
- Insensitive to aerodynamic instability
- No control surfaces needed (quadrotor)
- Low power usage in level flight
- Significantly higher cruise speed
- Significantly higher service ceiling
- No moving parts apart from motors

Cons:

- Not as aerodynamically efficient as a monoplane
- Sensitive to wind in hover mode due to large lateral surface area
- Sensitive to Center of Gravity changes

2.3 Tiltrotor monoplane aircraft

Fig. 4. Tiltrotor platform [3]

Tiltorotor monoplane configuration is a good compromise between a classic configuration airplane and a standard VTOL model

Pros:

- Aerodynamically efficient
- Hand launching possibility - battery saving on take-off
- Insensitive to wind in both level flight and hover mode
- Stable in level flight - good for video recording

Cons:

- Complicated engine rotating mechanism
- Difficult to create a compact size aircraft that is easy to assemble and consists of few parts

2.4 Standard monoplane VTOL

Fig. 5. Monoplane VTOL platform [4]

A standard monoplane is very simple to design and test, but has many disadvantages.

Pros:

- Simple to design and build
- Stable in level flight-good for video recording

Cons:

- Two sets of engines need to be used, one for propulsion during level flight, another for hover flight
- Unnecessary weight due to two engine sets
- High drag caused by unused engines in level flight resulting in worse performance

1.5 Tiltwing aircraft

Fig. 6. Tiltwing platform [5]

It is a complicated platform with a mechanism that rotates the wings in order to transform to a copter.

Pros:

- Aerodynamically efficient, all of the mechanisms are hidden in the fuselage – this results in low drag

Cons:

- Very complicated wing rotating system must withstand high loads caused by the bending moments on the wings. This would result in large weight of the mechanism and the whole airplane.

1.6 Final choice

Having considered advantages and disadvantages of the previously mentioned platforms, we decided to reject a multicopter because of short flight time, a standard VTOL because of its poor aerodynamic efficiency and

a tiltwing aircraft because of complicated and heavy construction. Therefore, we were left with two solutions: tailsitter and tiltrotor.
We decided to perform test flights of the two solutions. We used quadrotor tailsitter flying wing, and a tricopter tiltrotor monoplane, where the back engine is used only in hover mode, and the two front engines rotate, enabling forward flight.
During testing, we performed many observations and drew conclusions. The tailsitter performed very well in both hover and forward flight mode in calm weather conditions. When the wind velocity was higher than 7 m/s the platform was barely flyable in hover mode because of large surface area. The tiltrotor also performed well in both flying modes and was insensitive to winds as high as 12 m/s. The only problem we encountered was the sensitivity of platform to the engine location in level flight mode and we had to make careful calculations of the pitching moment in order to make it fly.
After performing test flights, we decided the tiltrotor configuration fulfills our requirements in the best way, as a good surveillance drone must perform well in various weather conditions. The maximum wind velocity of 7 m/s is just not enough.
Having chosen the configuration and confronting it with reality during the test flights we were able to assess optimal dimensions of our aircraft. Mass analysis was based on density of the materials and the weight of electric components, as they influence the take-off weight and barely depend on the vehicle size. Maximum load of the plane is limited by the minimal velocity (9m/s) that occurs during hand launching. While assessing the thrust of the engines in hover mode, 20% control margin for control is required.
Aerodynamic performance was calculated basing o the vehicle size and confronted with the ones of the prototype to assess its correctness.
The graph shows max. take-off weight and endurance in level flight and hover mode in the function of the wingspan. It appears that performance increases with the wingspan, which simultaneously is limited by the backpack size to 1,8 m, as we want our construction to be compact and easy to carry. Another imposed restriction is its maximal weight of 4 kg conditioned by the required possibility of hand launching.

3 Optimization

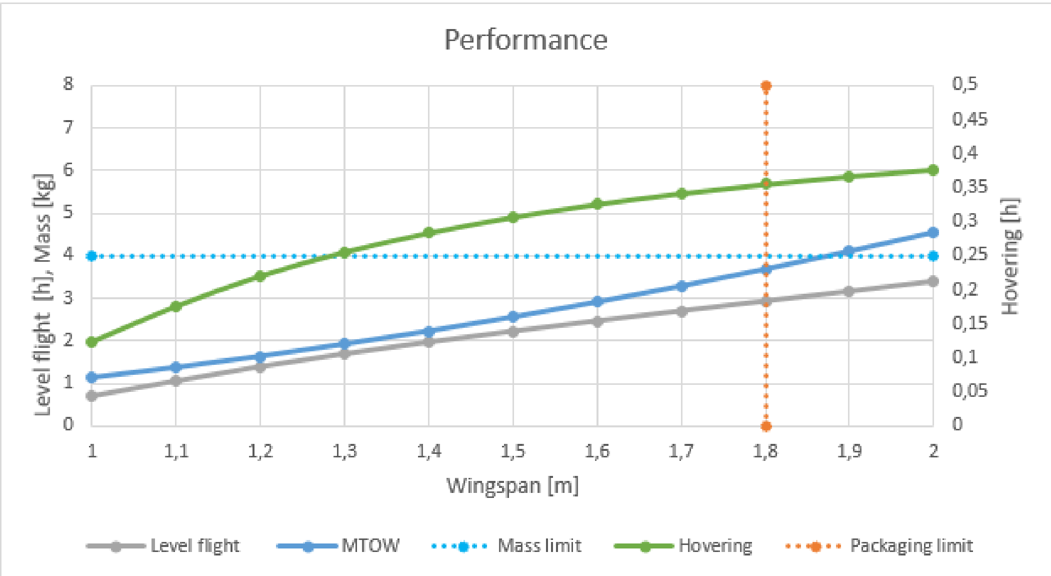

Fig. 7. Performance analysis

Table 2. Vehicle size and performance

Wingspan	1800	mm
Lenght	1500	mm
Height	300	mm
Construction mass (w/a batteries, payload, engines)	712	g
Equipment mass	441	g
Engines mass	341	g
Battery mass	2192	g
Thrust of engines	4609	g
MTOW	3687	g
Endurance of level flight	176	min
Endurance of Hovering	22	min
Carrying box length	700	mm

3 Trend analysis

The trend analysis showed that there are a lot of superior performance aircraft on the market that are hard to compete with. The main problem is that majority of them need favorable conditions such as long runway, time and great amount of equipment that may be impossible to carry during some missions. There are not many constructions that fulfill the requirements of quick recognition mission such as patrolling the area by the mountain rescuers to find potential injured.

Our goal was to design compact construction that fits the backpack, is ready fly in a few minutes and is able to launch and land even in very small area such as wood, between the buildings, etc. We decided that MICRODRONE should be able to convert from high performance aircraft to rotorcraft that is sufficient to move the construction to desired flight level or to hover above the object while recognition.

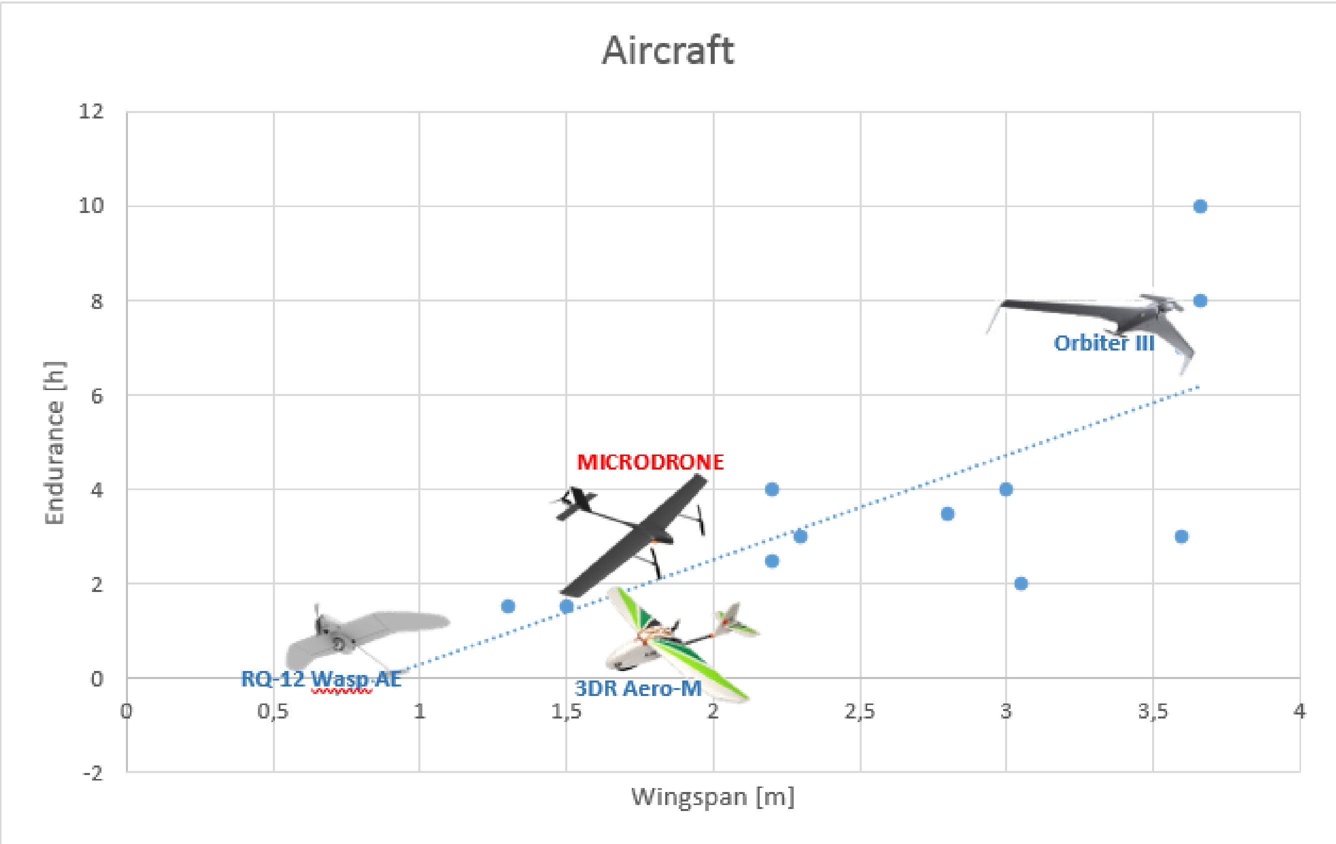

Fig. 8. Aircraft trend analysis [6,7,8]

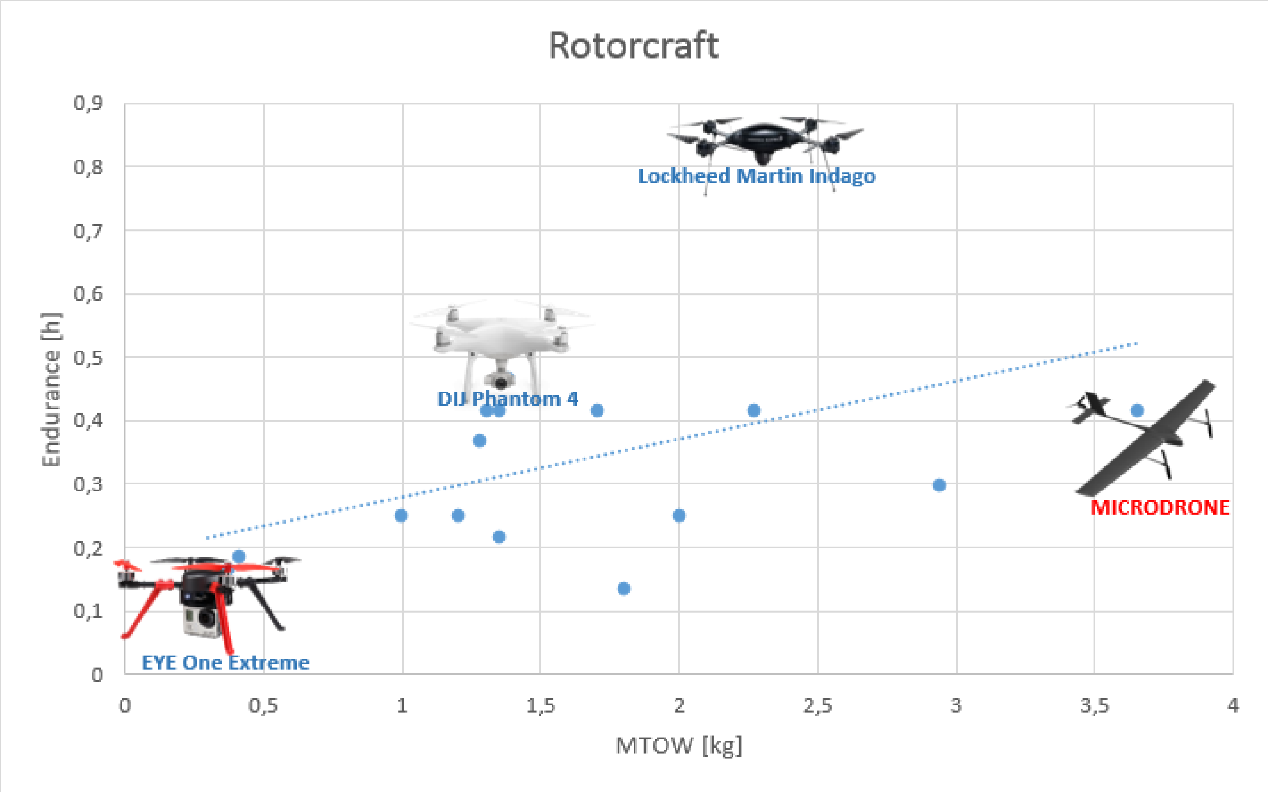

Fig. 9. Rotorcraft trend analysis [9,10,11]

Our multi-purpose aircraft will be able to fly up to 3 hours what is definitely sufficient to meet imposed requirements and places it above the average considering constructions powered by electric engines.

As a rotorcraft MICRODRONE only has to be able to hover for a few minutes or start and land vertically. That is why its high performance as a tricopter is simply unnecessary – 22 minutes of flight is satisfying result.

6 Mission Profile

The graph [Fig. 10] shows the exemplary mission profile MICRODRONE fulfills. The aim is to patrol certain area and find the object of interest to perform its detailed surveillance. After hand launching the aircraft is able to fly the distance of 30 km and than stay in hover mode for over 12 minutes. After gathering required material MICRODRONE comes back home in level flight mode and than lands vertically. The whole mission lasts 90 minutes. Thanks to MICRODRONE's versatility it can be adjusted to various environmental and weather conditions, size and the type of patrolled area and observed object. Its endurance depends on the launching method, altitude and the time spent in hover mode.

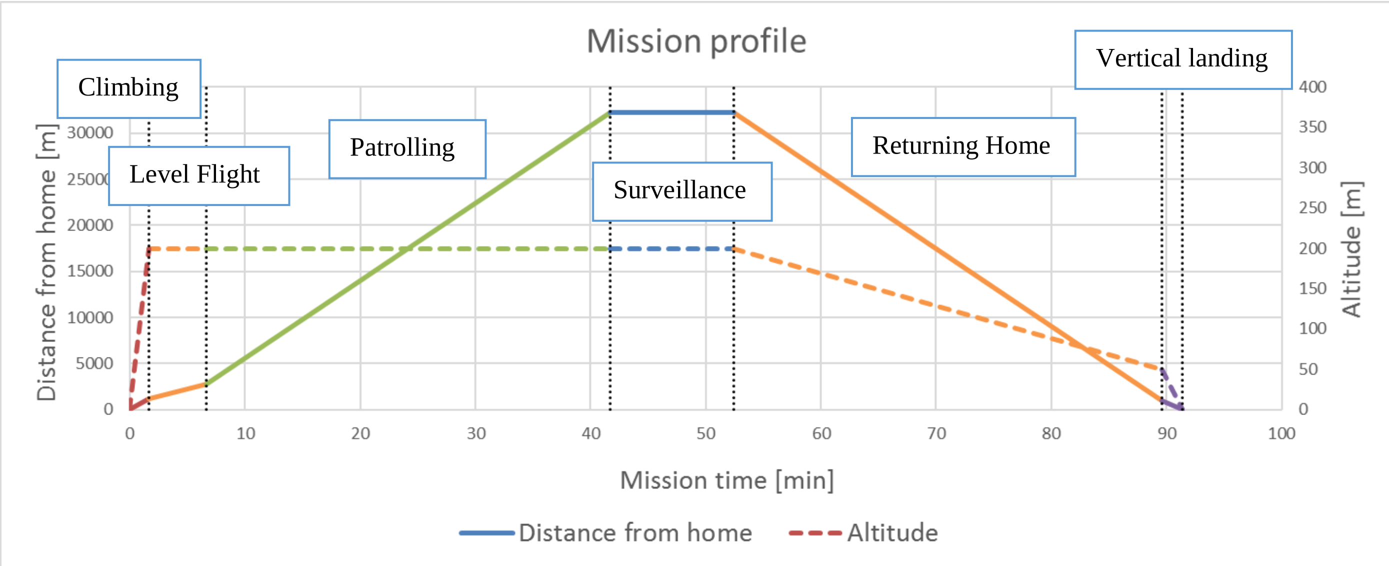

Fig. 10. Mission profile

7 Final Effect

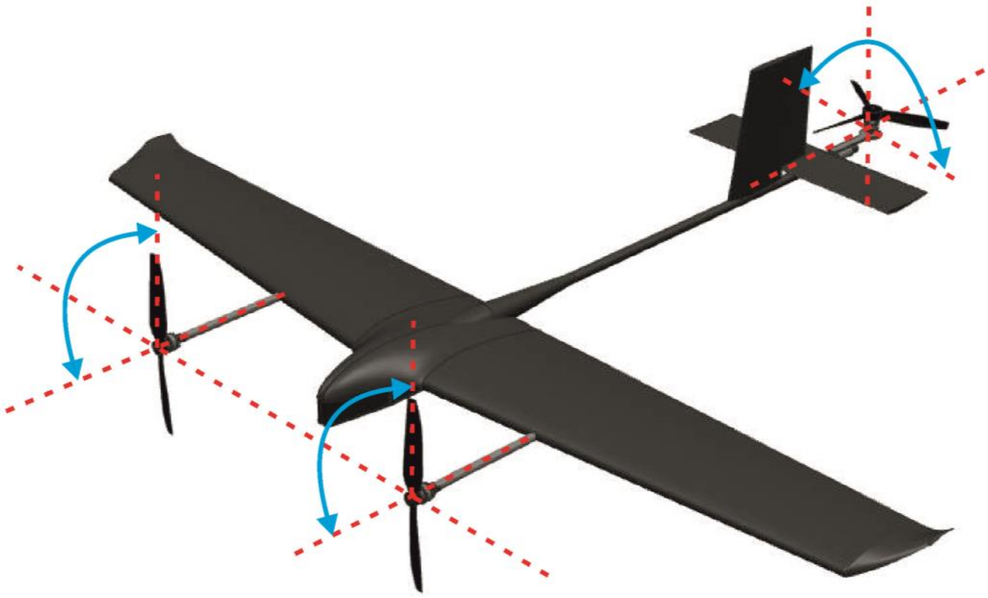

Fig. 11. MICRODRONE

What we came up with is the classic configuration monoplane that can easily convert to the tricopter. The aft engine is used only in hover mode. To make it smallest possible we placed it far from the Center of Gravity and therefore did not increase drag during level flight. Front engines rotate to implement mode transition. The wing consists of three equal length parts to provide compact packaging and small bending moment on the joints. Telescopic tailboom and fuselage permanently integrated with the centerwing simplify the assembly, which can be accomplished in six quick steps.
The sandwich structure wing and the stabilizers

are made mostly with the use of carbon fiber. The fuselage construction enables both vertical and horizontal belly landing.

Our high-lift aircraft makes it possible to use classic or thermographic camera with mechanical stabilization and battery that provides high endurance.

References

[1] www.directindustry.com/industrial-manufacturer/quadrotor-uav-86139.html 28.06.2016

[2] www.wired.com/2014/08/google-reveals-project-wing-its-two-year-effort-to-build-delivery-drones/ 28.06.2016

[3] www.koreabizwire.com/korea-to-commercialize-tilt-rotor-drone-by-2023/33506 28.06.2016

[4] www.pixhawk.org/_detail/platforms/vtol/fun_cub/img_3886.jpg?id=platforms%3Avtol%3Afun_cub_quad_vtol 28.06.2016

[5] www.rcgroups.com/forums/showthread.php?t=2166752%23post28579162tak 28.06.2016

[6] www.uasvision.com/2015/06/22/australian-defence-force-starts-training-with-aerovironments-rq-12-wasp-ae/?utm_source=inside&utm_medium=link. 28.06.2016

[7] www.3dr.com/wp-content/uploads/2014/10/AeroM-Operation-Manual-v1.pdf 28.06.2016

[8] www.aeronautics-sys.com/orbiter_mini_uav_muas 28.06.2016

[9] www.rclogger.com/RC-EYE/RC-EYE-One-Xtreme/RC-EYE-One-Xtreme-Mode-2.html 28.06.2016

[10] www.dji.com/product/phantom-4/info#specs 28.06.2016

[11] www.lockheedmartin.com/us/products/procerus/indago-uas.html 28.06.2016

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