Safety Memo

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Notations

n	Life time in amount of charge / discharge cycle
e	Endurance (h)
h	Cruise Altitude (m)
L/D	Lift-to-Drag ratio
ws	Wind speed (m/s)
as	Air speed (m/s)

1. Safety Properties

The Vehicle (Fig. 1)

Length:	33cm
Span:	60cm
Weight:	270g
Velocity:	6-8m/s

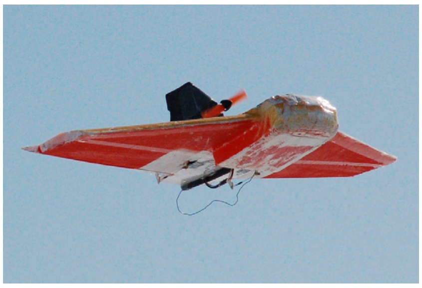

Figure 1: MANTA

Transmission Systems

RC receiver for manual control:	GWS R-4PII/H 4chPICO TYPE
RC transmitter for manual control:	AIRTRONICS INC RD 6000 Super
Wireless modem for uplink and downlink:	YOKOYAMA Co., Ltd YM-503 5mW

Flight Control System

The system is equipped with flight computer (Fig.2). Many sensors and electronic devices can be connected. Rate gyros, GPS antenna, barometric altimeter, geomagnetism sensor, RC receiver and wireless modem are used and autonomous waypoint tracking is attained.

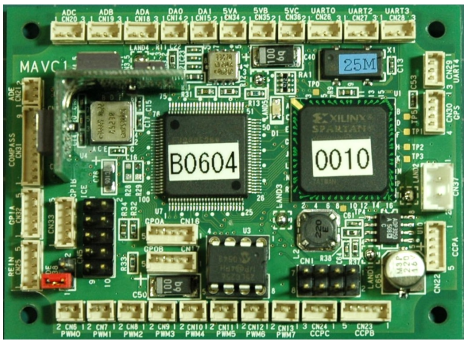

Figure 2: Flight computer (MAVC1)

2. Flight Performance

Autonomous waypoint tracking can be attained using flight control system. Positions and altitudes of the waypoints are defined in program. Flight data are transmitted to the base and commands are sent to the vehicle. Figure 3 shows the results of waypoints tracking experiments. The vehicle can remain in the 140m square zone.

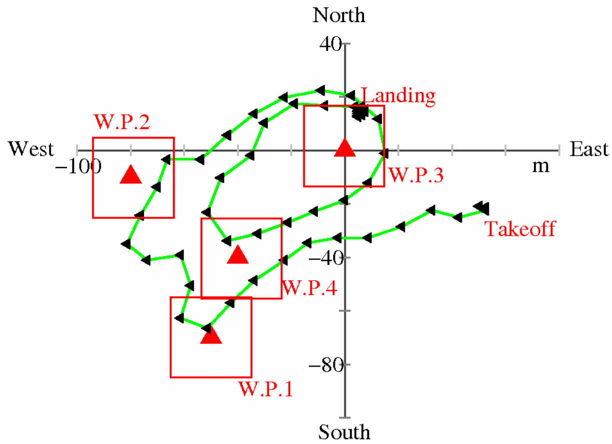

Figure 3: Waypoints tracking experiments

3. Safety system

- Operator monitors GPS status, vehicle position and altitude.
- Operator can override the control using RC transmitter anytime.
- When the GPS link failure or RC transmitter failure occurs, flight computer cuts the throttle and lands the vehicle quickly.

4. Flight Zone Computation

The fall distance without wind is: $L/D \times h$

The fall duration is: $\dfrac{\sqrt{h^2 + (L/D \times h)^2}}{as}$

The wind effect is: $\frac{\sqrt{h^2+(L/D\times h)^2}}{as}\times ws$

Therefore, we have (see Fig. 4):

$$d = L/D\times h+\frac{\sqrt{h^2+(L/D\times h)^2}}{as}\times ws$$

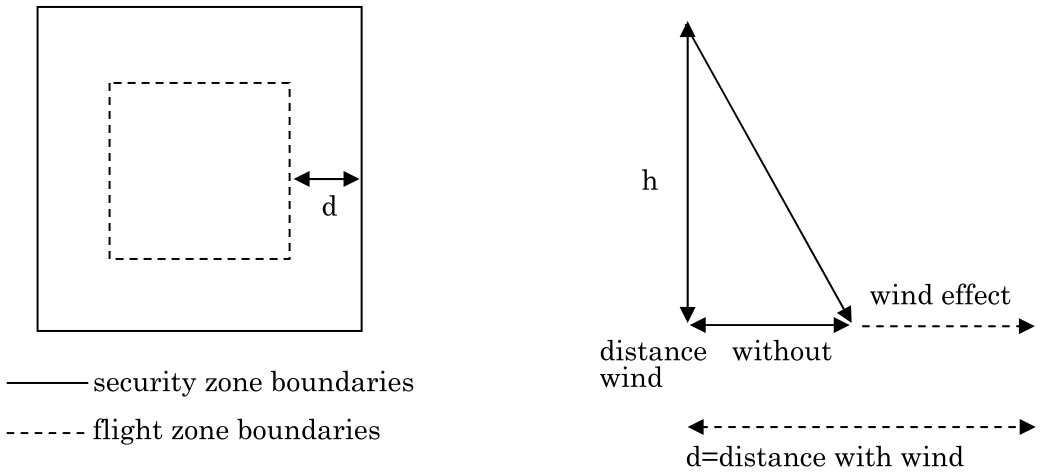

Figure 4: On the left: distance between the Security zone and the Flight zone. On the right: How the previous distance is computed

The vehicle cruise speed is approximatively 8m/s. At this speed the maximum Lift-to-Drag ratio is 3. In the worse case, we consider that the wind speed is 8m/s. Air speed is 8 m/s and cruise altitude is 5m. The Li-Po battery commonly used have a 2000 charge and discharge cycle, and provides a 0.5 hour endurance. Therefore we have a distance:

d=46 meters

5. Probability to exit a given flight zone

To prevent vehicle from causing accidents we need to classify flight failure and provide manoeuvers and failsafes to prevent this failures to be responsible for an accident. To do so a vehicle mustn't exit a given flight zone with the probability of 10^{-4} per flight hour.

Power supply failure

A power supply failure will automatically and immediatly cause a crash of the MAV.

We define the following events, which are indepent:

A The battery of the vehicle is out of order.

B The vehicle crash outside of the borders of the flight zone.

$$P(A)=\frac{1}{n\times e}=1.0\times10^{-3} \text{ per hour}$$

$$d = L/D \times h + \frac{\sqrt{h^2 + (L/D \times h)^2}}{as} \times ws = 46 \text{ meters}$$

$$P(B) = \frac{surface(strip\ within\ distance\ d\ of\ the\ borders)}{surface(flight\ zone)} = 0.0567$$

$$P(A \cap B) = P(A) \times P(B) = 5.67 \times 10^{-5} \text{ per hour}$$

To simplify the computation of the surface we considered that the flight zone was a 800 meters square.

GPS failure

If the vehicle lose the GPS fix more than 2s, the only way to avoid the vehicle to exit the flight zone is the safety RC link. If the RC link is also lost we shut down the throttle to make it crash safely.

We consider the events:

A GPS signal failure

B RC link failure

C The vehicle crash outside the flight zone

Based on previous flight experience (more than 100 flights of 10 minutes average since 2005) we had one GPS fix failure during a flight. Therefore, the typical GPS failure probability is estimated to:

$$P(A) = \frac{1}{100 \times 10/60} = 6.0 \times 10^{-2} \text{ per hour}$$

Based on FFAM estimated figures of year 2006 of 5 accidents due to lost of RC link per year and per club with 737 clubs and 23692 members (50 h/yr/member) we estimated the probability of losing RC link to:

$$P(B) = \frac{5 \times 737}{50 \times 23692} = 3.11 \times 10^{-3}$$

From previous section we have:

$$P(C) = 5.7 \times 10^{-2}$$

Therefore, as A, B, and C are independent events:

$$P(A \cap B \cap C) = P(A) \times P(B) \times P(C) = 1.06 \times 10^{-5} \text{ per hour}$$

Autopilot failure

If the autopilot fails the only way to get the aircraft on the ground and inside the flight zone is to use the safety RC link. Let A = Autopilot fails and B = Lost RC link. Over more than 100 flight hours we hadn't experienced any autopilot failure, therefore:

$$P(A) < \frac{1}{100} = 1 \times 10^{-2}$$

We have:

$$P(A \cap B) = P(A) \times P(B) < 3.11 \times 10^{-5} \text{ per hour}$$