Safety Memo

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The University of Arizona Wildcat Team is participating in the outdoor competition using the MAV system Raptor. Raptor is a fully autonomous MAV system. Autonomous micro air vehicles must be able to fly in the rural areas, as well as in densely populated cities. Therefore, the main requirement for an autonomous MAV is its safety of operation and safety of flight. The autopilot system used on Raptor is the Paparazzi[1] development system. The Paparazzi system is programmed to Raptors needs with safety and ease of use in mind. The following are safety features incorporated into the Raptor MAV system:

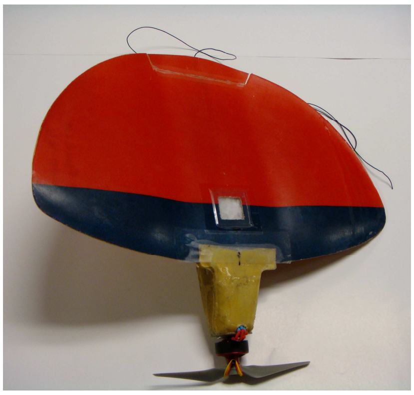
1. Currently, the RC unit is used as a command link to the vehicle and as an emergency mode of control for the autonomous vehicle. At any moment of flight, the autonomous mode of operation can be overridden, and manual control of the airplane can be imposed using the RC unit.
2. As an additional safety measure, the airplane is assigned an in-plane circular boundary. When the airplane is in a restricted area, it switches to the "home mode" or "reversion mode," and the airplane navigates to a pre-assigned location–the "home waypoint"–and circles at a constant predetermined altitude until an explicit command for normal flight is received.
3. If the command link is lost, and it is not restored in 10 sec, the airplane switches to the reversion mode, as described in item 2.
4. There are several rules forced on the autopilot in case of failure of the important electronic components, such as the autopilot, GPS unit, and battery. When the autopilot fails, a special indicator of downlink signal loss appears on the screen of the ground station. In this case, a safety pilot overrides the autonomous mode and operates the vehicle manually, according to item 1. In the case of GPS unit failure, the airplane lands immediately, by assigning and keeping a safe landing mode attitude. In the case of battery failure, the airplane reduces thrust to zero and glides to the ground.
5. All safety features and flight schematics can be modeled in the flight simulator on the ground station before the flight.

Nomenclature

n	Lifetime in amount of charge/discharge cycle
e	Endurance
h	Cruise Altitude
L/D	Lift to Drag Ratio
ws	Wind Speed
as	Air Speed

System Properties

Airframe



Name	Raptor
Weight	220g
Wingspan	30cm
Propulsion	1 Electric Brushless Outrunner Motor
Endurance	20 minutes

Figure 1. Raptor Outdoor MAV

Transmission Systems

- 2.4 Ghz analog transmitter for video downlink (50mW)
- X-Bee Digital Modem 2.4Ghz for uplink and downlink telemetry and data (50mW)
- 72Mhz RC transmitter for safety RC link (100mW)

Autopilot system

Figure 2. Paparazzi Tiny Board

As stated earlier, the Paparazzi autopilot system is used. Figure 2 shows the Paparazzi Tiny Board that is used with Raptor. The autopilot software performs navigation of the airplane and communication with external devices, such as infrared board and GPS. The autopilot has three modes – fully autonomous mode, augmented stability mode, and fully manual mode. These modes can be selected by an operator from the ground station.

Flight Zone Computation

In order to compute the distance the MAV flies in the event of an emergency landing, the following parameters are used:

L/D 1-4
h 20m
as 10m/s
ws 15m/s (worst case scenario)
e 20mins

Equations Used:

Emergency Landing Distance (without wind) - $\mathbf{d_{nw}}$

$$d_{nw} = L/D \times h = 80\text{m}$$

Emergency Landing Duration (without wind) - $\mathbf{t_{nw}}$

$$t_{nw} = \frac{\sqrt{h^2 + (L/D \times h)^2}}{as} = 8.25\text{s}$$

Emergency Landing Distance with wind, $\mathbf{d_w}$, is calculated assuming that MAV is descending with L/D = 1.5 giving

$$d_w = L/D \times h + \frac{\sqrt{h^2 + (L/D \times h)^2}}{as} \times ws = 153.75\text{m}$$

Probability to exit a given flight zone

In order to prevent an MAV from exiting the flight zone being able to execute safety maneuvers is critical. These maneuvers must be such that the MAV is prohibited from leaving the flight zone with a probability of 10^{-4} per flight hour.

Power Supply Failure:

In the event that the MAV has a major power failure the MAV will make a controlled crash landing. Let A= Battery of MAV is out of power

$P(A) = \frac{1}{n * e} = 1.67*10^{-5}$

GPS Failure[2] :

If the Micro Air Vehicle lose the GPS fix more than 2s, the only way to avoid the MAV 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 Micro Air Vehicle crash outside the flight zone Based on previous flight experience (more than 400 flights of 20 minutes average since 2003) we had one GPS fix failure during a flight. Therefore, the typical GPS failure probability is estimated to:

$$P(A) = \frac{1}{400 * \frac{20}{60}} = \frac{1}{120} = 7.5 * 10^{-3} \text{ per hour}$$

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:

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

From previous section we have:
$P(C) = 1.25 \times 10-1$
Therefore, as A, B, and C are independent events:
$P(A \cap B \cap C) = P(A) \times P(B) \times P(C) = 1.25 \times 10-6$ per hour

Autopilot Failure:

In the event of autopilot failure the only way to regain control of the aircraft is if the RC pilot takes over. Let A = Autopilot failure. Over 200 hours of flight testing without any autopilot failure was experienced, thus.

$$P(A) < \frac{1}{200} = 5*10^{-3}$$

Therefore,

$P(A \cap B) = P(A) \times P(B) < 1.244 \times 10-5$ per hour

References:

[1] P. Brisset, A. Drouin, M. Gorraz, P.-S. Huard, and J. Tyler. The Paparazzi solution. In MAV2006, Sandestin, Florida, November 2006.
[2] Pierre-Selim Huard. GPS Failure. In MAV2007 Safety Memo, Toulouse, France, September 2007.