



The M.A.C.'06 MAV

A Paparazzi based
autonomous aircraft

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Build your own

$$m \ddot{\vec{r}} = \vec{F} = -\alpha (\dot{\vec{r}} + \vec{v}_{wind}(z))^2 \frac{\dot{\vec{r}} + \vec{v}_{wind}(z)}{|\dot{\vec{r}} + \vec{v}_{wind}(z)|} - m g \vec{e}_z$$

With

m : mass of the ball (3.31g)
 $\ddot{\vec{r}}$: acceleration of the ball
 \vec{F} : sum of all external forces

$$\alpha = \frac{1}{2} \rho A c_w$$

$A = \pi R^2$

R : radius of the ball
 c_w : drag coefficient of a sphere (0.45)
 ρ : density of air depending on pressure, temperature and humidity (1.184 kg/m³ at standard conditions)

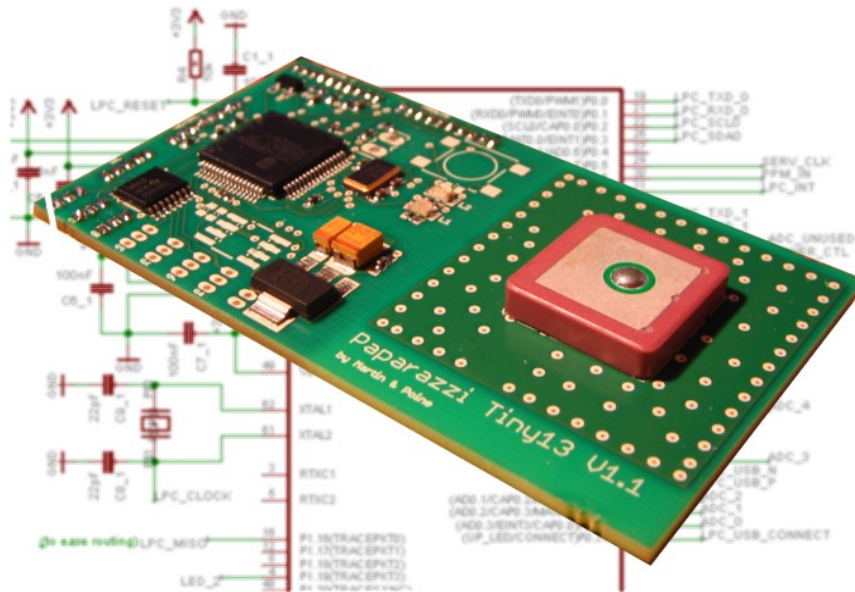
\vec{r} : position of the ball
 $\vec{v}_{wind}(z)$: wind velocity vector depending on the altitude (wind shear)
 $\dot{\vec{r}}$: velocity of the ball
 g : gravitational acceleration (9.81 m/s²)
 \vec{e}_z : unit vector in vertical direction



```
beta = ... / (air.vy + air.vz*air.vz);

// using Euler's differential equation
// velocity of the ball
ball->vx = ball->vx + dt * (air.vx * beta);
ball->vy = ball->vy + dt * (air.vy * beta);
ball->vz = ball->vz + dt * (air.vz * beta - GRAV_ACC);

// position of the paint ball
ball->x = ball->x + dt * ball->vx;
ball->y = ball->y + dt * ball->vy;
ball->z = ball->z + dt * ball->vz;
```

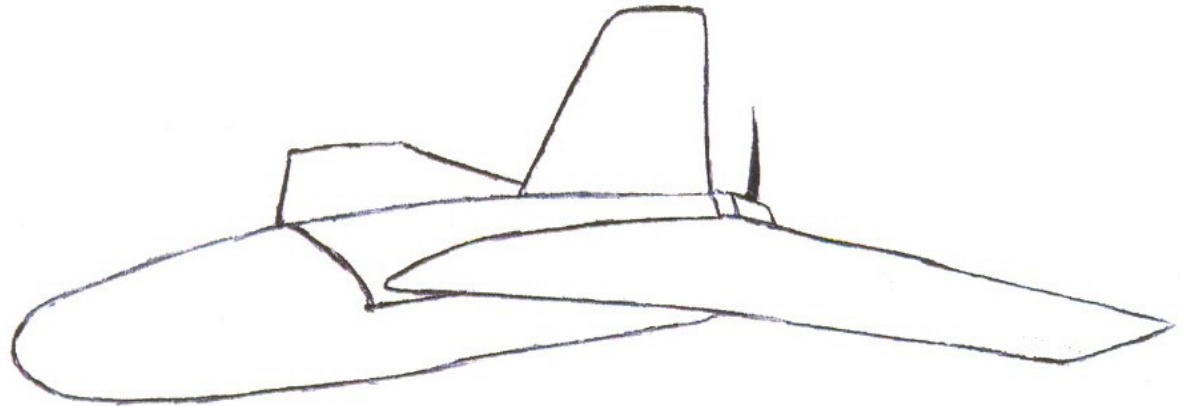




Airframe

Design goals

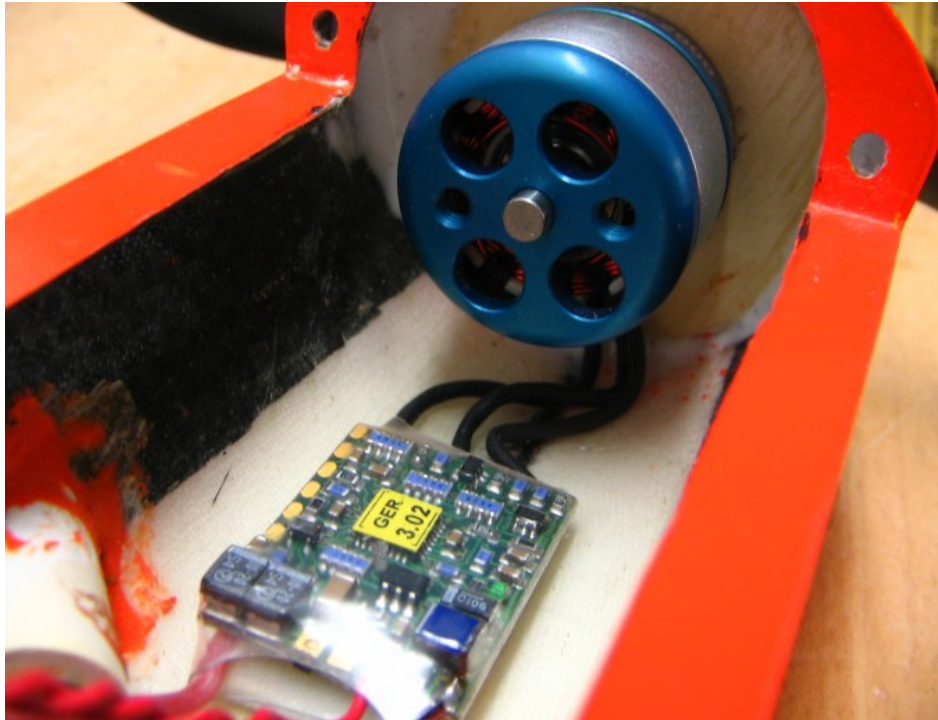
- size according to MAV'06 competition rules
- overall weight max. 300g
- maximize camera stability by stable flight



> Airframe is done from EPP (glass / carbon in custom molds)



Propulsion System



- propeller: 4.7x4.7 APC
- motor: Flyware 220-6-2800 (brushless outrunner)
- controller: TMM 7A
- battery: PolyQuest 2 cell 1200mAh LiPo
- flight time: 20 minutes



Paparazzi Software

Paparazzi GCS

Nav Maps Edit Help TMM1 52.270489 10.009055 1.00

TMM1 101.39 9.99 m/s

HOME

TMM1 00:13:18 04:10 00:10 00:00:00

AP	AUTO2	alt	174.4	->	147.4	
12.5	RC	OK	climb	-0.1	->	-0.7
GPS	3D	speed	10.0	throttle	43.6	

Center A/C Send WPs Mark

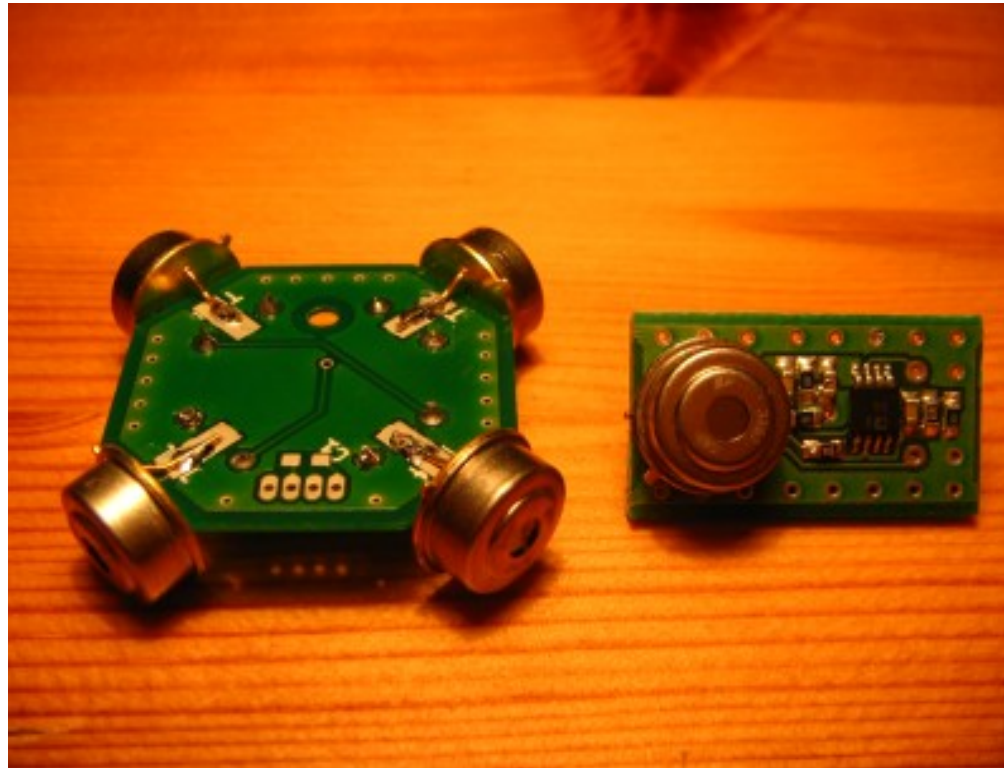
20:27:30 TMM1, AUTO2
20:27:31 TMM1, start
20:27:35 TMM1, wp21
20:27:48 TMM1, wp12
20:30:17 TMM1, wp21
20:31:09 TMM1, wp12
20:31:48 TMM1, wp21

TMM1

Flight Plan Infrared GPS PFD Misc Settings



Sensors - Attitude



PerkinElmer TPS334 infrared thermopiles
(far infrared 5-14 μm)



Sensors – 3D Position/Speed



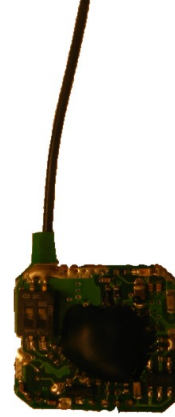
u-blox LEA-4P GPS receiver, 4Hz update rate, ceramic patch antenna, mounted on autopilot board inside aircraft



Communication



*analog
RC uplink*



*analog
video downlink*



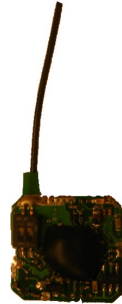
*digital
2-way data link*



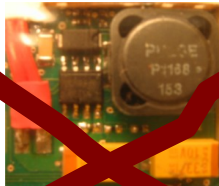
Electromagnetic Interference



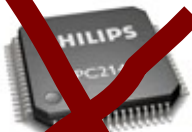
telemetry
900MHz
25mW



video
2.4GHz
50mW



supply
250kHz
1.5A



processor
2..60MHz



IR sensor
~100µV



GPS
1.575GHz



RC
35MHz



telemetry
900MHz

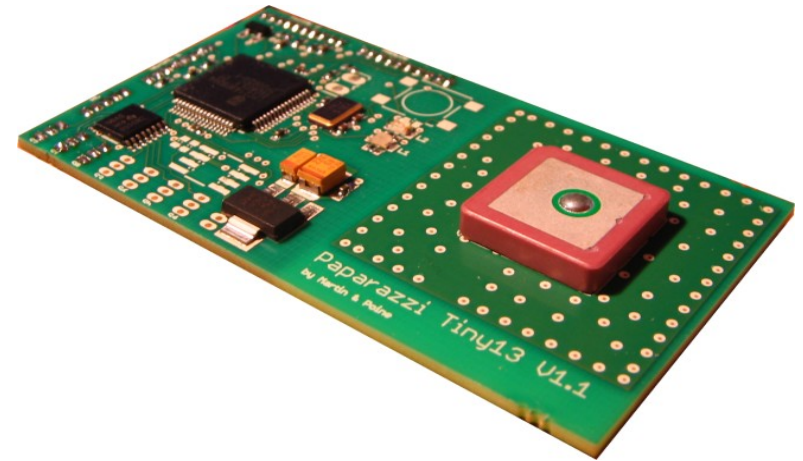




Autopilot Tiny

Improvements since MAV'05

- processor, power supply, GPS on one board with common ground
- smaller (64 x 36mm)
- lighter (19g)
- 32bit ARM7 core @ 60MHz
- fast USB flashing





Payload - Roll Camera



coordinate transformation

$$\mathbf{x}'_{\text{obj}} = \mathbf{R} * (\mathbf{P} * (\mathbf{T} * (\mathbf{x}_{\text{obj}} - \mathbf{x}_{\text{MAV}})))$$

cartesian ->

spherical polar coordinates

camera points towards target

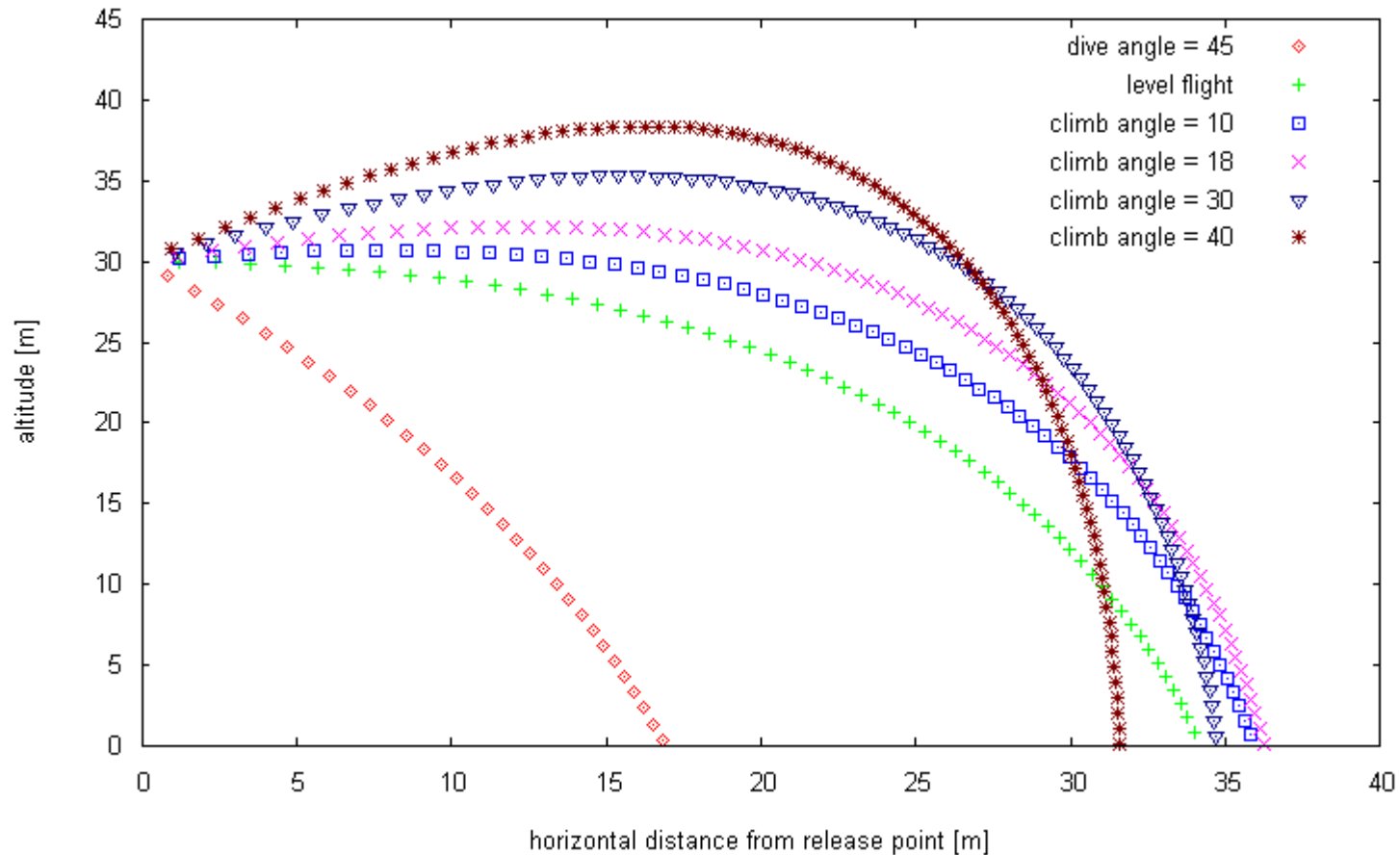


Payload – Sensor Drop





Sensor Drop - Trajectories



Aircraft speed 25m/s, wind speed 5m/s



Sensor Drop - Accuracy

	45° dive	horizontal flight	18° climb
deployment distance	17,1 m	34,2 m	36,3m
wind speed	0,7 m / (m/s)	1.7 m / (m/s)	2,5 m / (m/s)
wind direction (head wind 10 m/s)	0.0005 m / ° in flight direction 0.046 m / ° perpendicular to flight direction	0.0013 m / ° in flight direction 0.1 m / ° perpendicular to flight direction	0.0018 m / ° in flight direction 0.15 m / ° perpendicular to flight direction
release height	0,26 m / m	0,4 m / m	0,11 m / m
release velocity	0,27 m / (m/s)	1,3 m / (m/s)	1,13 m / (m/s)
plane direction	0,49 m / °	0,7 m / °	0,83 m / °
plane climb angle	0,34 m / °	0,3 m / °	0,0 m / °
release time	10,2 m / s	25 m / s	24,5 m / s
release position in / perpendicular to flight direction	1 m / m (simple offset)	1 m / m (simple offset)	1 m / m (simple offset)
paint ball weight	1,2 m / g	4,8 m / g	6,2 m / g
paint ball diameter	0,65 m / mm	2,1 m / mm	2,7 m / mm
barometric pressure	0,008 m / mbar	0,02 m / mbar	0,024 m / mbar



Weights

<i>module</i>	<i>weight</i>
airframe	76g
engine with controller	30g
propeller	2g
battery	58g
infrared sensor	8g
processor board, GPS receiver, antenna, power supply	19g
flight servos	10g
900MHz telemetry transceiver	6g
35MHz receiver	8g
2,4GHz video transmitter	8g
camera unit with rotate servo	10g
paint ball release mechanism	5g
total	240g



Paparazzi Team

