

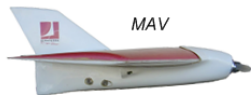
# The Paparazzi UAV System

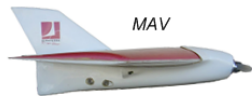
Pascal Brisset

ENAC

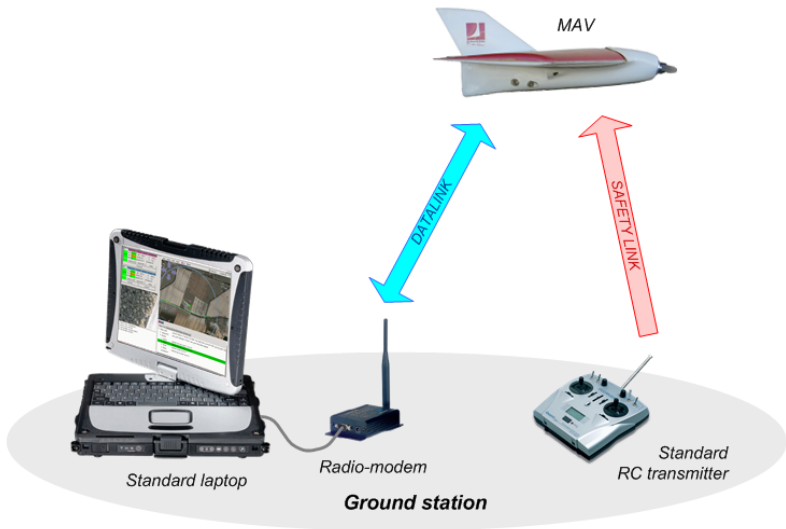
Solutions Linux, March 2010

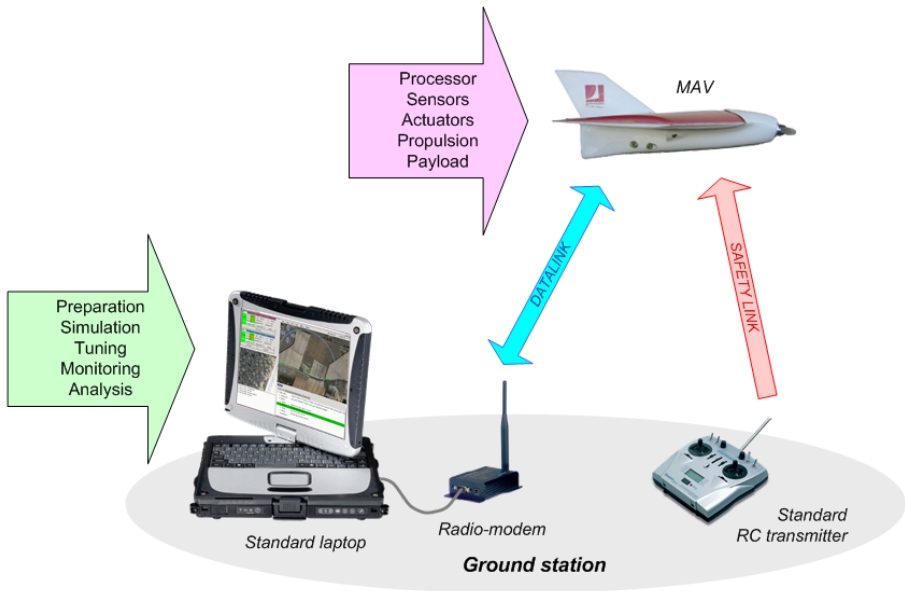






*Standard  
RC transmitter*





# Experiments with MAVs



- From 1.4m down to 0.3m
- From 1.4kg down to 250g
- From 1 to 5 vehicles
- From 20min to 60min
- 10km away, 3500m high
- From India to



# Experiments with MAVs



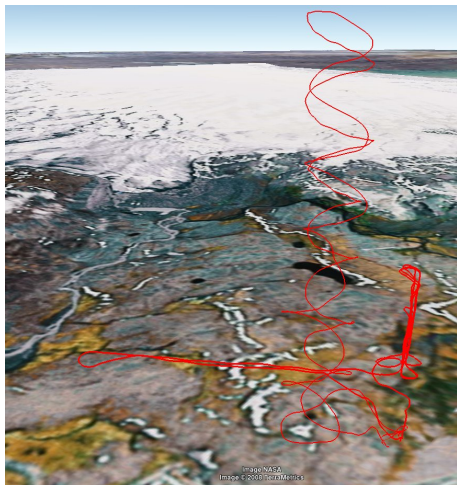
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- From 1.4kg down to 250g
- From 1 to 5 vehicles
- From 20min to 60min
- 10km away, 3500m high
- From India to



# Experiments with MAVs



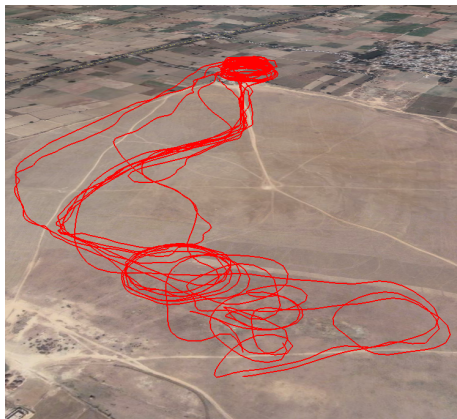
- From 1.4m down to 0.3m
- From 1.4kg down to 250g
- From 1 to 5 vehicles
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# Experiments with MAVs



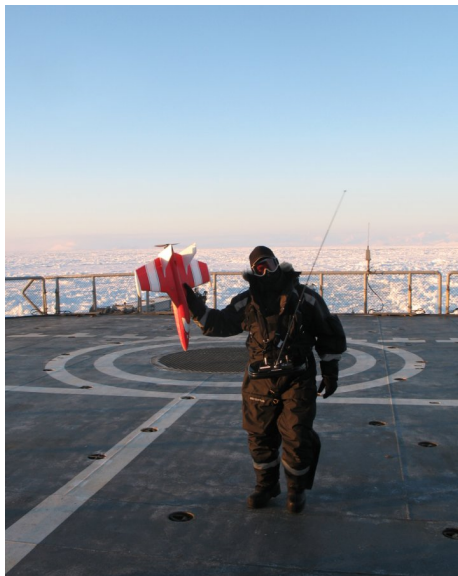
- From 1.4m down to 0.3m
- From 1.4kg down to 250g
- From 1 to 5 vehicles
- From 20min to 60min
- 10km away, 3500m high
- From India to



# Experiments with MAVs



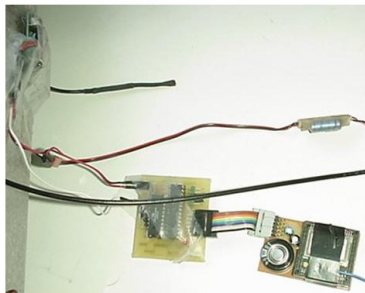
- From 1.4m down to 0.3m
- From 1.4kg down to 250g
- From 1 to 5 vehicles
- From 20min to 60min
- 10km away, 3500m high
- From India to Artic



# History of the Project



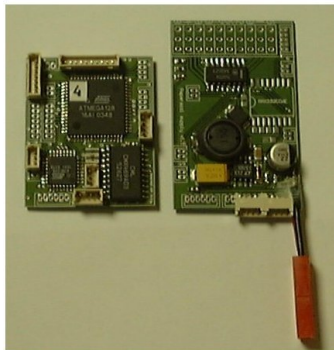
2003



# History of the Project



2004



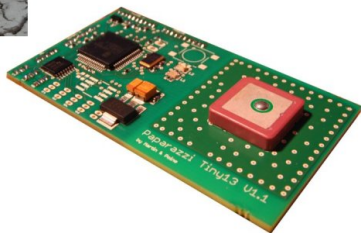
# History of the Project



2005



# History of the Project



2006

# History of the Project

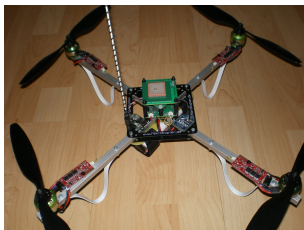


2007

# History of the Project



2008



# History of the Project



2009







# Paparazzi: The Free Autopilot



`paparazzi.enac.fr`

## Goals

- Autonomous flight
- Safety
- Low cost
- Open source



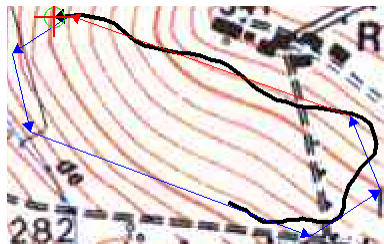
# Paparazzi: The Free Autopilot



`paparazzi.enac.fr`

## Goals

- Autonomous flight
- Safety
- Low cost
- Size
- *Open source*



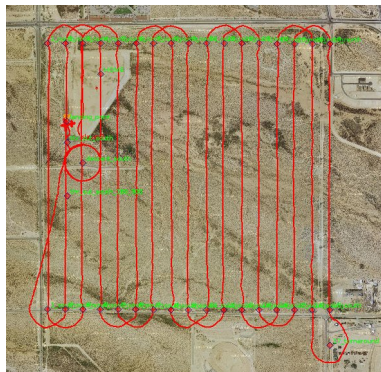
2003



`paparazzi.enac.fr`

## Goals

- Autonomous flight
- Safety
- Low cost
- Size
- *Open source*



2006



# Paparazzi: The Free Autopilot



`paparazzi.enac.fr`

## Goals

- Autonomous flight
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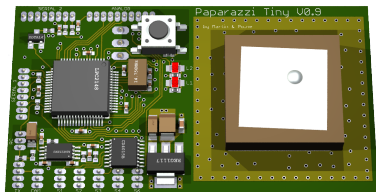




`paparazzi.enac.fr`

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- Autonomous flight
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- Low cost
- Size
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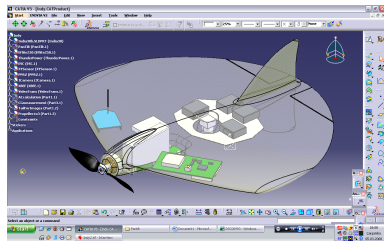
# Paparazzi: The Free Autopilot



`paparazzi.enac.fr`

## Goals

- Autonomous flight
- Safety
- Low cost
- Size
- *Open source*





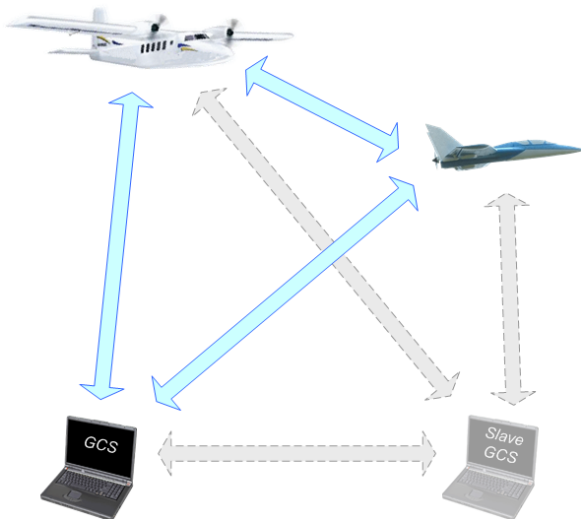
`paparazzi.enac.fr`

## Goals

- Autonomous flight
- Safety
- Low cost
- Size
- *Open source*



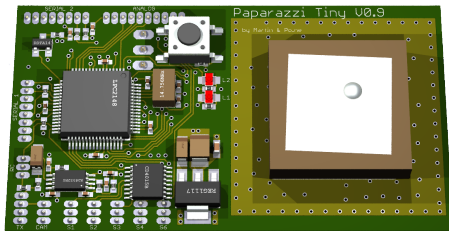
# The Paparazzi System



# Autopilot

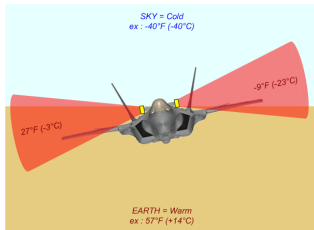
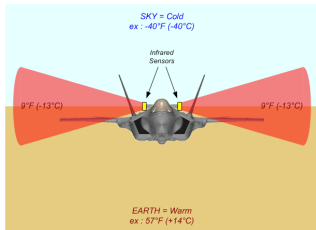


- Processor
- GPS
- Power supply
- 20g



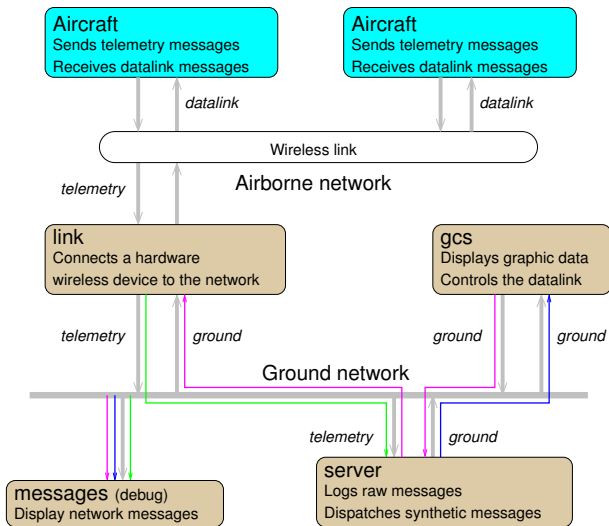


## Attitude Estimation with Infrared



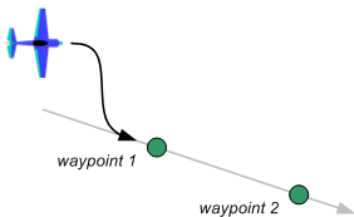


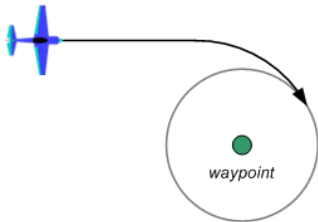
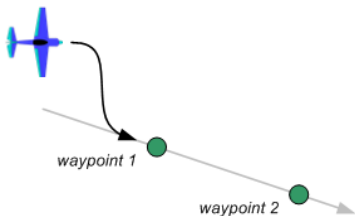
# Distributed System

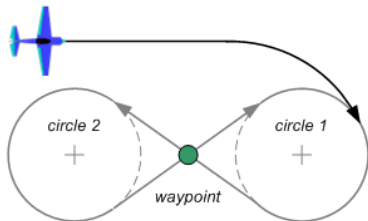
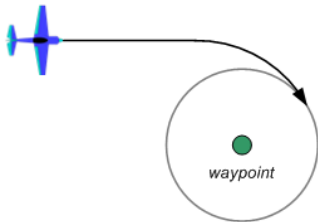
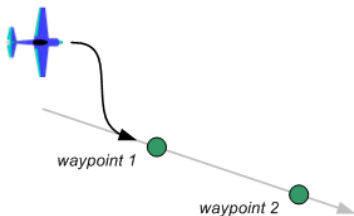




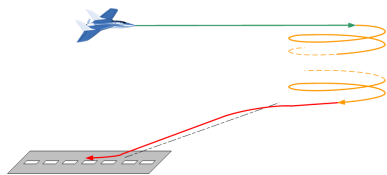
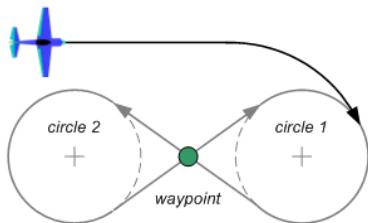
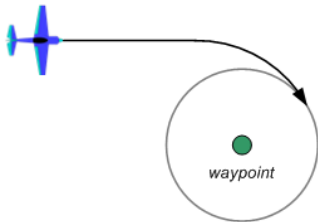
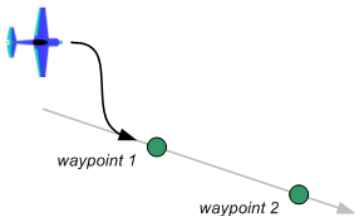
# Flight Plan

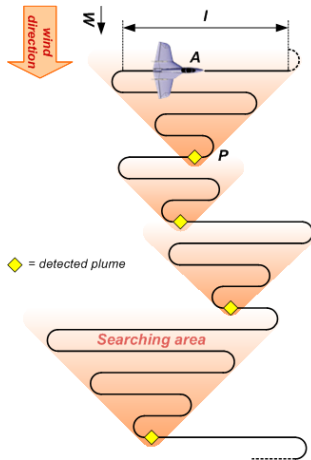






# Flight Plan







# A Versatile Interface



Nav Maps Help T1J1 M12 WGS84 43.462499 1.271362 1.56

**2D Map**

**T1J1**  
 00:00:35 **11.6m/s** **43%** Standby  
 Bat Status AGL Block Nav  
 12.5 AUTO2 67 Time 00:26  
 NONE +0.1 Stage 00:26  
 Link 3D /Target Alt  
 -6m 254m / 260m

**M12**  
 00:00:20 **12.1m/s** **10%** Standby  
 Bat Status AGL Block Nav  
 12.5 AUTO2 62 Time 00:22  
 NONE +0.0 Stage 00:22  
 Link 3D /Target Alt  
 -11m 249m / 260m

**Strips**

**Notebook**

**Console**

13:46:59 T1J1 UNK  
 13:46:59 T1J1 mayday, kill mode  
 13:47:01 M12, AUTO2  
 13:47:01 M12, mayday, kill mode  
 13:47:02 M12, Geo init  
 13:47:04 T1J1, Holding point  
 13:47:11 M12, Holding point  
 13:47:58 T1J1, Takeoff  
 13:48:05 M12, Takeoff  
 13:48:07 T1J1, Standby  
 13:48:11 M12, Standby





# To be free (or not to be)



## Software

- GNU/Linux Debian and Ubuntu
- GCC for x86, AVR, ARM...
- OCaml compiler, runtime and libraries (XML, network...)
- GTK Toolkit (OCaml bindings), glade generator
- Ivy software bus
- Subversion
- Mediawiki

## Hardware Design

- Eagle (freeware and academic licence)
- Protel



# To be free (or not to be)



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# Paparazzi Contents



What Paparazzi makes available, under GPL:

- Source code (C, OCaml, XML...)
- Board schematics and layout (Eagle, Protel and Gerber formats)
- Documentation (GNU FDL)

How:

- Subversion server ([svn.savannah.gnu.org](http://svn.savannah.gnu.org))
- HTTP server: archives, Debian and Ubuntu packages, live CD image
- Wiki ([paparazzi.enac.fr](http://paparazzi.enac.fr))



# Paparazzi Contents



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# MAV Competitions



- JMD03, Toulouse, France: 1st place with the Twinstar
- EMAV04, Braunschweig, Germany: 1st place with the Microjet
- JMD04, Toulouse, France: 1st place with the Microjet
- MAV05, Garmisch, Germany: 4 Paparazzi teams at the first 4 places
- EMAV06, Braunschweig, Germany : all the teams were equipped with Paparazzi
- MAV06, Sandestin, Florida: 2nd and 3rd places
- MAV07, Toulouse, France: 1st place (tie), 3rd, 4th and 5th places
- MAV08, Agra, India: Tie
- Concours DGA 08-09: 1st with a quadrotor
- IMAV09, Pensacola, Florida: 1st place (ISAE)
- AUVSI (Students), Maryland: 1st place (Utah State University)



# Martin Müller Engineering, Germany



Martin Müller is one of the main contributors of the project.



## Active since 2004

- MAV05
- Iceland, 2007
- Spitzberg, 2008
- Spitzberg, 2009



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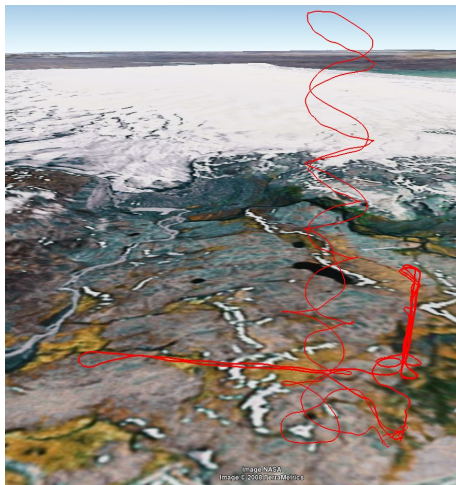
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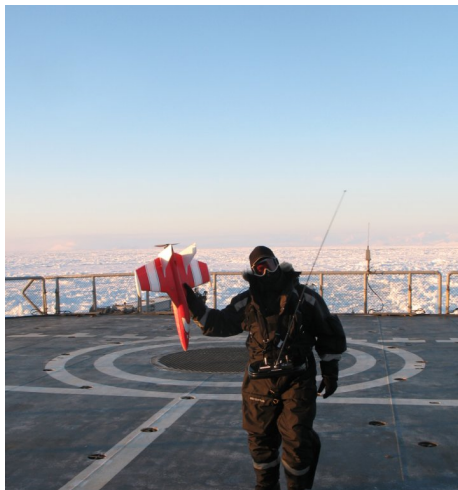
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- Spitzberg, 2009





# Hardware Providers



http://ppzuav.com

**PPZUAV**  
Complete Solutions for Paparazzi UAV

Categories

Accessories -> (34)  
Tiny Adaptor (7)  
Assembled (7)  
Base PCBs (7)  
Misc

Navigation: Home, Products, News, Contact Us

Please Select

What's new?

receiver board \$25.00

Quick Find

Use keywords to find the product you are looking for. **Advanced Search**

Information

Shipping & Returns  
Privacy Notice  
Conditions of Use  
Contact Us

## What's New Here?

Welcome **Guest!** Would you like to [log yourself in?](#) Or would you prefer to [create an account?](#)

**PPZUAV.com** - A company Providing quality components and information for the construction of a Paparazzi Project based UAV's. Paparazzi Project is a free and open-source hardware and software project being used and developed at ENAC University. For information about ENAC or The Paparazzi Project please go to the Wiki page: <http://paparazzi.enac.fr/>

At PPZUAV we provide community members with quality components, discount pricing and exceptional customer service. Our PCB assembler assemblies are fabricated and assembled in Facilities following strict ISO 9002/ISO 9001 and IPC standards.

As community members ourselves, we stand behind everything we sell.

Please look around and feel free to contact us at [sales@ppzuav.com](mailto:sales@ppzuav.com) with any questions, comments or suggestions. Thank you!

**IMPORTANT!** PPZUAV, LLC. Reserves the right to refuse the sale of any or all of these products to anyone for any reason or where prohibited by law. **BY ORDERING FROM THIS SITE YOU AGREE** to the following: These items are sold as-is and without warranty. PPZUAV, LLC. is not responsible for any kind caused by the use of these products. You are assuming all responsibility for your actions and all consequences while using these products.

New Products by Pap July

 <b>SPK External GPS board LEA-3H</b> \$125.00	 <b>ADXR561D</b> \$150.00	 <b>receiver board</b> \$25.00
 <b>PPM Decoder Board Bare PCB</b> \$1.49	 <b>Bundle 8: TW09 HQ GPS</b> \$979.00	 <b>Bundle 7: TW09 HQ GPS</b> \$410.00

http://chebuzz.com/paparazzi

Home Log In Enter search keyword Search

**chebuzz**  
paparazzi

## Your EU Paparazzi Supplier

Complete Systems Modules Components Cables

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Welcome Guest! Would you like to [log yourself in?](#)

Welcome to CheBuzz Paparazzi!

**Credit card processing has been approved and is now ready!** It is now our preferred payment method. Note, I do not store CC numbers on my site. All processing is done through authorize.net. Product photos are almost all completed. If you have any suggestions/recommendations, please feel free to contact me using the webform on this site. Thanks for visiting.

Categories

Complete Systems (2)  
Modules (8)  
Components (9)  
Cables (7)

New Products ...  
All Products ...

Reviews [more]

Great purchase. The level of service you'll get is awesome! \*

★★★★★

Information

Shipping & Returns  
Conditions of Use  
Contact Us  
Site Map  
Newsletter unsubscribe

Authorize.net Merchant

Authorize.net e-Check

### New Products For July

 <b>Tiny to USB (board)</b> \$10.00	 <b>LISY300AL 300 degree/sec Gyro</b> \$25.00	 <b>Aerocomm AC4790 Modem</b> \$55.00
 <b>TW09 v1.0 PCB</b> \$5.00	 <b>PPR2 GPS v1.3 PCB</b> \$10.00	 <b>PPM Encoder PCB</b> \$3.00
 <b>TW09 v1.0</b>	 <b>PPR2 GPS v1.3</b> \$80.00	 <b>"Everything is a TW09"</b>

New Products [more]

NO PICTURE AVAILABLE

U-blox LEA-5H GPS module \$60.00

Melexis MLX90247 IR sensors \$10.00

Picoblade to Servo Adapters \$2.50

Bestsellers

- Picoblade to Servo Adapters
- Melexis MLX90247 IR sensors
- Tiny 2.11 PCB
- "Everything you need" kit
- Tiny to IR
- Tiny to IRH



# Fly'n'Sense, Bordeaux, France



<http://www.fly-n-sense.com/>



Home Company Contact

A company which

- is using the Paparazzi autopilot;
- got training from ENAC;
- is selling a micro UAV system;
- sells service and consulting.

## Products

- Presentation
- Operation
- Product Range

## Services

## Applications



Home • Products • Product Range

## Product Range

Fly-n-Sense flagship product : FNS900-Seeker

Micro-UAV system type fixed-wing with integrated fuselage, FNS 900 Seeker aims to give a complete and performance airborne solution for missions of **Intelligence, Surveillance and Reconnaissance**.

With an autopilot incorporated inside, it can accomplish missions in autonomous or assisted mode, repeated or not, even by an unskilled operator.

Provided with a powerful software, a ground station controls the Seeker and enables real-time transfer of the data collected from different on-board systems, fitted according to the mission.



FNS900-Seeker: dimensions 90cmx75cm

A promising project in partnership with the initiative Scancopter

SCANCOPTER project aims to develop VTOL micro-UAV applications for environmental, safety, or industry. Quick and easy to operate (vertical



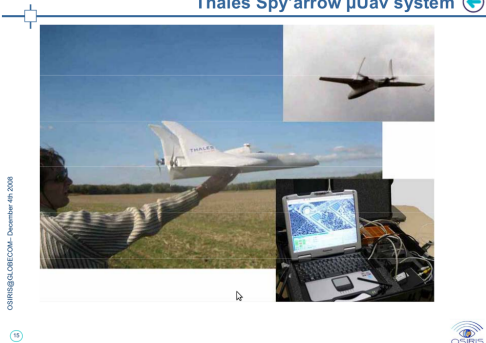


# Thalès Robotics, France



- Got a contract with ENAC in 2005
- Demonstate a Paparazzi Aircraft in 2008
- Advertize it at the Paris Air Show in 2009

## Thales Spy'arrow $\mu$ Uav system

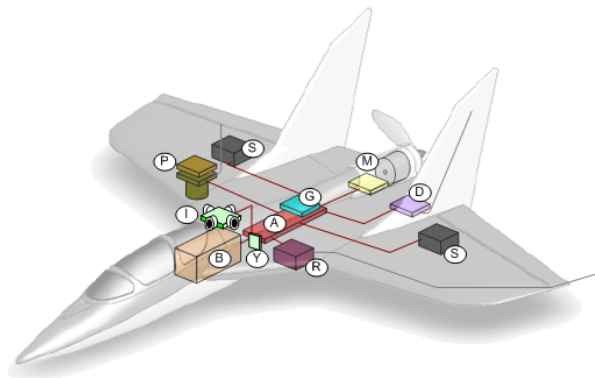


(from [http://newton.ee.auth.gr/aerial\\_space/docs/CS\\_4.pdf](http://newton.ee.auth.gr/aerial_space/docs/CS_4.pdf))

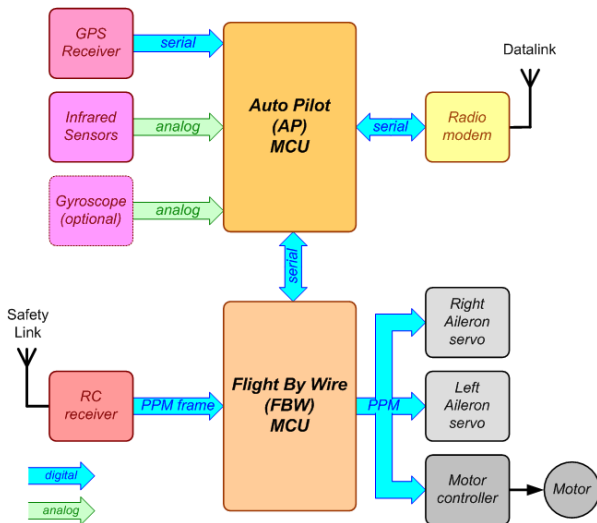




**A** utopilot  
**B** attery  
**D** atalink  
**G** PS  
**I** nfrared  
**M** otor  
**P** ayload  
**R** eceiver  
**S** ervo  
**GY** ro



# Airborne Hardware







# Configure, Compile, Upload and Run



**Paparazzi Center**

A/C Session Tools View Help

A/C id GUI color Target Session

TJ1 6 [Color] sim Simulation Execute

**Configuration** **Building** **Execution**

airframes/twinjet1.xml ... Edit

Flight plan

flight\_plans/versatile.xml ... Edit

Settings

settings/tuning.xml ... Edit

Radio

radios/cockpitSX.xml ... Edit

Telemetry

telemetry/default.xml ... Edit

Clean Build Upload

Stop/Remove All Processes

GCS /home/pascal/pprz/savannah/paparazzi3/ [Stop] [Remove]

Server /home/pascal/pprz/savannah/paparazzi3/ [Stop] [Remove]

Simulator /home/pascal/pprz/savannah/paparazzi3/ [Stop] [Remove]

**Running Agents**

**Console**

```
CC /home/pascal/pprz/savannah/paparazzi3/var/TJ1/sim/sim_gps.o
CC /home/pascal/pprz/savannah/paparazzi3/var/TJ1/sim/sim_ir.o
CC /home/pascal/pprz/savannah/paparazzi3/var/TJ1/sim/sim_ap.o
CC /home/pascal/pprz/savannah/paparazzi3/var/TJ1/sim/ivy_transport.o
CC /home/pascal/pprz/savannah/paparazzi3/var/TJ1/sim/nav_survey_rectangle.o
CC /home/pascal/pprz/savannah/paparazzi3/var/TJ1/sim/nav_line.o
CC /home/pascal/pprz/savannah/paparazzi3/var/TJ1/sim/bomb.o
LD /home/pascal/pprz/savannah/paparazzi3/var/TJ1/sim/simsitl
make[1]: Leaving directory `/home/pascal/pprz/savannah/paparazzi3/sw/airborne'
make: Leaving directory `/home/pascal/pprz/savannah/paparazzi3'
Run '/home/pascal/pprz/savannah/paparazzi3/sw/ground_segment/cockpit/gcs '
Run '/home/pascal/pprz/savannah/paparazzi3/sw/ground_segment/tmtc/server -n'
Run '/home/pascal/pprz/savannah/paparazzi3/sw/simulator/launchsitl -a TJ1 -boot -norc'
/home/pascal/pprz/savannah/paparazzi3/var/TJ1/sim/simsitl
```

HOME=/home/pascal/pprz/savannah/paparazzi3 SRC=/home/pascal/pprz/savannah/paparazzi3



# Flight Plan



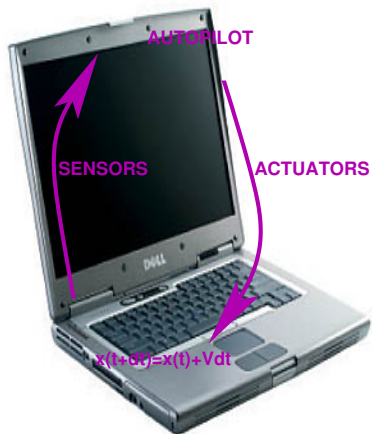
## Three Elements

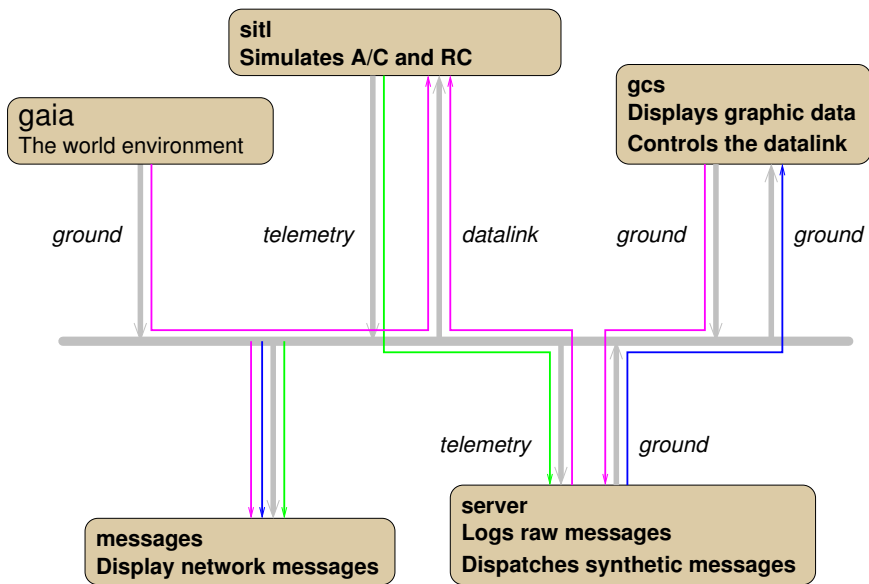
- Header: Localization
- Waypoints
- Blocks: sequences of instructions

```
<flight_plan name="Muret" lat0="43.46223" lon0="1.27289"
    max_dist_from_home="300"
    ground_alt="185" security_height="50" alt="250">
  <waypoints>
    <waypoint name="HOME" x="0" y="0"/>
    <waypoint name="AIRWAY" x="80" y="20" alt="185"/>
    ...
  </waypoints>
  <blocks>
    <block name="cercle"><circle radius="100" wp="HOME"/></block>
    <block name="glide12">
```



- Autopilot compiled for the x86 host
- Simulator
  - Flight Model
  - Sensors
  - Actuators

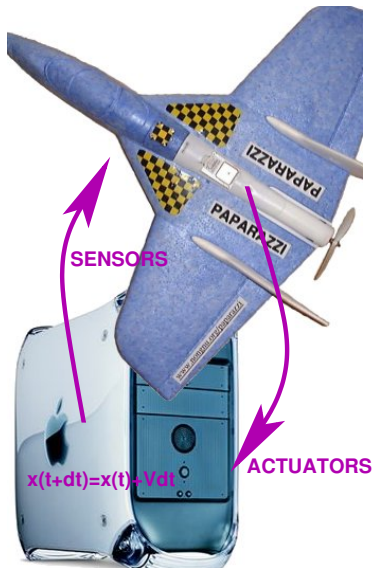


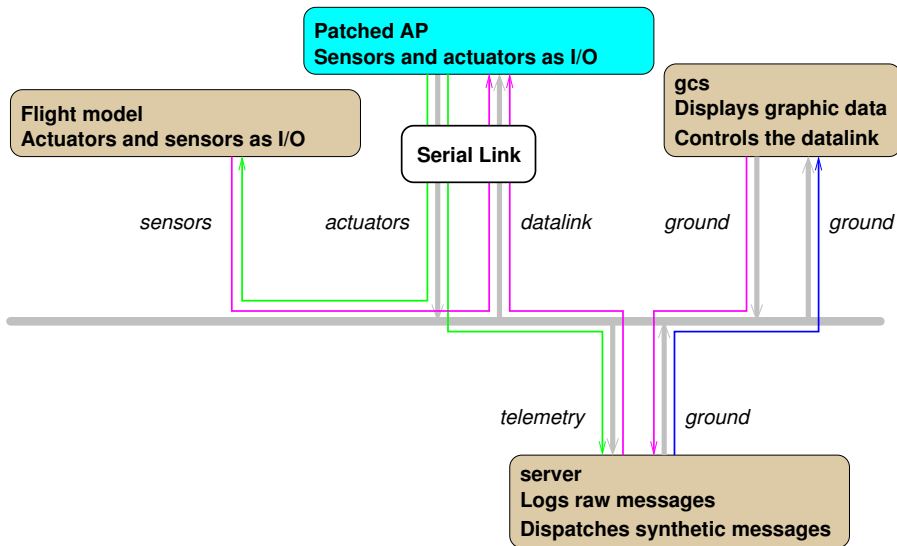


# Hardare In The Loop Simulation



- Autopilot running on airborne hardware
- Sensors replaced by serial input
- Actuators replaced by serial output
- Simulator



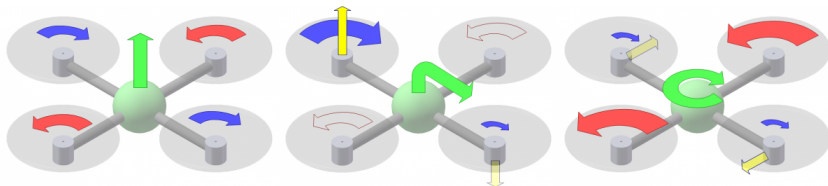




# Flight control principles



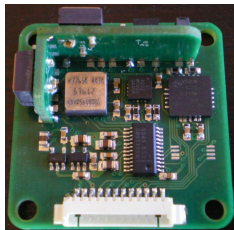
- No mechanical parts except motor propellers
- Control is achieved only by changing the motors' speeds





## Attitude estimation

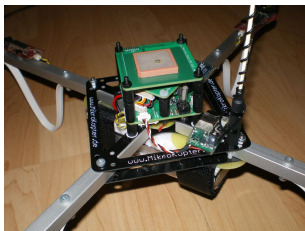
- Infrared sensors are not fast enough and can't be used indoor
- Inertial Measurement Unit (IMU) is needed but requires filters to estimate the attitude
- Gyroscopes and accelerometers are fused with a complementary filter
  - Gyro integration is fast but has a drift
  - Accelerometers measure the gravity and correct the drift





## Position and heading estimation

- Horizontal position and velocity : GPS receiver
- Altitude : barometer and accelerometers integrated with a Kalman filter
- Heading : complementary filter between gyroscopes and magnetometers





# Navigation



## Use existing interfaces

- Same flight plan mechanism
- Same GCS for all aircraft
- Most of the procedures are available for quads (waypoint, circle, segment, +hovering)



# Performances



- Endurance : 10 to 20 min
- Weight : 450 g, payload : 200 to 300 g
- Horizontal speed : 5 m/s controlled, 10 m/s max
- Vertical acceleration : 3g up, 1g down
- Horizontal accuracy : 5 to 8 m
- Vertical accuracy : 10 cm with important drift ! (several meters)
- Wind : flies with 10 m/s of wind but autonomous navigation abilities greatly reduced





# Flying Autonomously in a Few Steps



- 1 Get and build a model aircraft (airframe, servos, motor, controller, radio receiver, radio transmitter)



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- 5 Write a configuration for your aircraft
- 6 Upload the airborne code, start and throw
- 7 Have a drink while looking at the GCS



# Thanks



**PAPARAZZI**  
*The Free Autopilot*

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