Build your own UAV

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Ecole Nationale de l'Aviation Civile

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1. Overview
2. Flight Presentation
3. In Depth Description
   - Hardware
   - Software
   - Applications
4. Conclusions

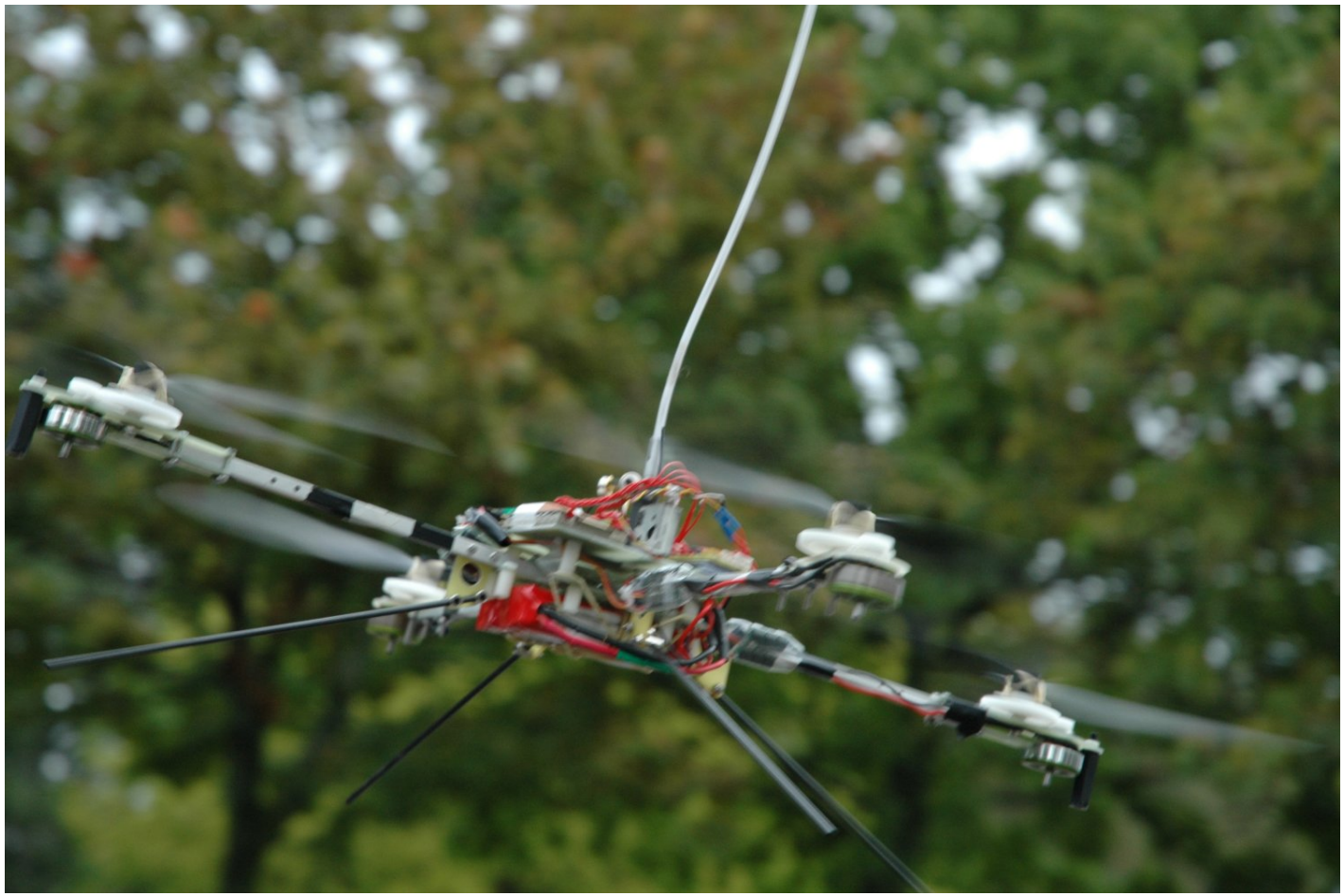
UAVs

UAVs

UAVs

UAVs

UAVs



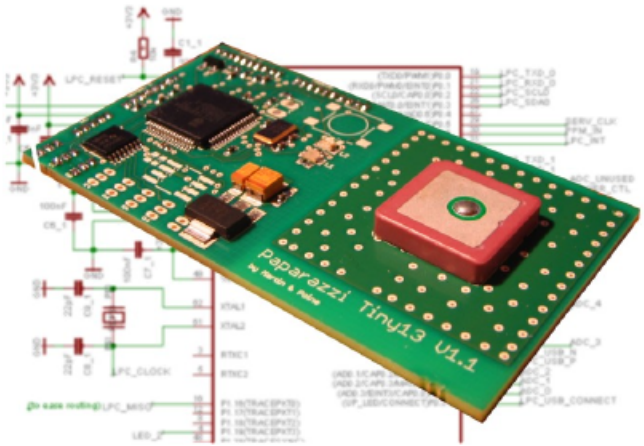
What it takes

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

With

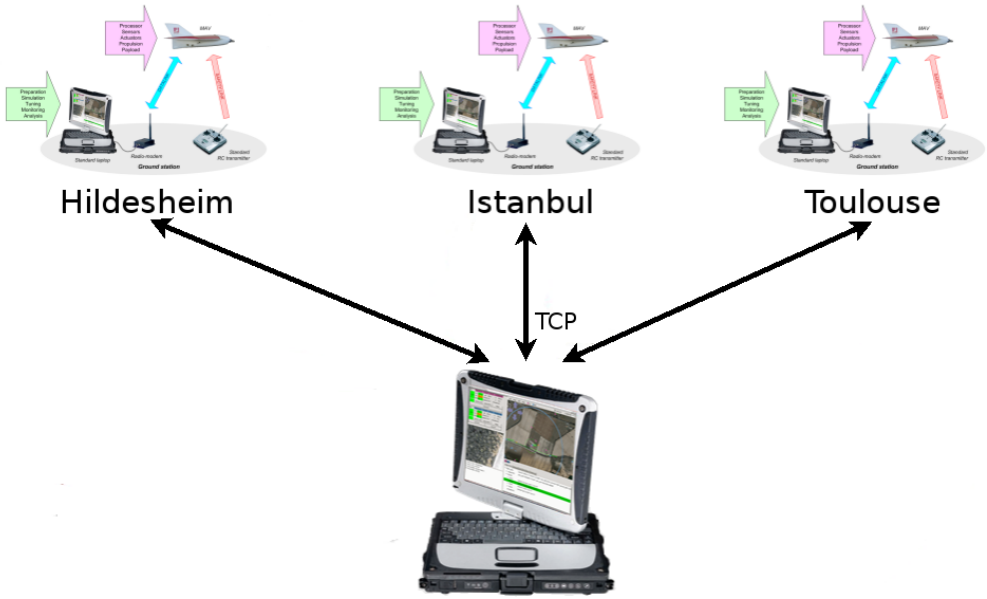
m:	mass of the ball (3.31g)
$\vec{\ddot{r}}$:	acceleration of the ball
$\vec{F}$:	sum of all external forces
$\alpha = \frac{1}{2}\rho A c_w$	
$A = \pi R^2$	
R:	
c_w:	drag coefficient of a sphere (0.45)
ρ:	density of air depending on pressure, temperature and humidity ($1.184\ kg/m^3$ at standard conditions)
$\vec{r}$:	position of the ball
$\vec{v}_{wind}(z)$:	wind velocity vector depending on the altitude (wind shear)
$\vec{\dot{r}}$:	velocity of the ball
g:	gravitational acceleration ($9.81\ kg\ m/s^2$)
$\vec{e}_z$:	unit vector in vertical direction

```
// 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;
```

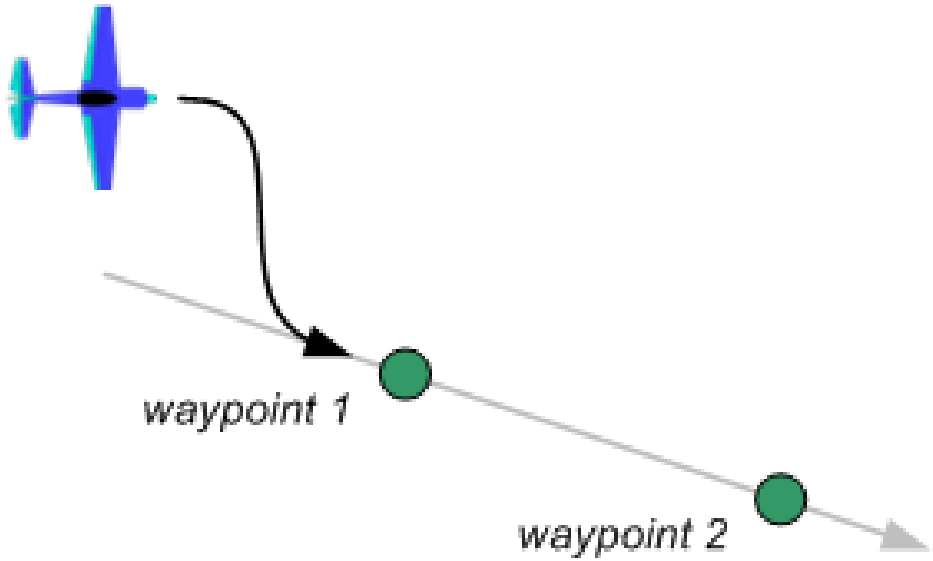


Unmanned Aircraft System

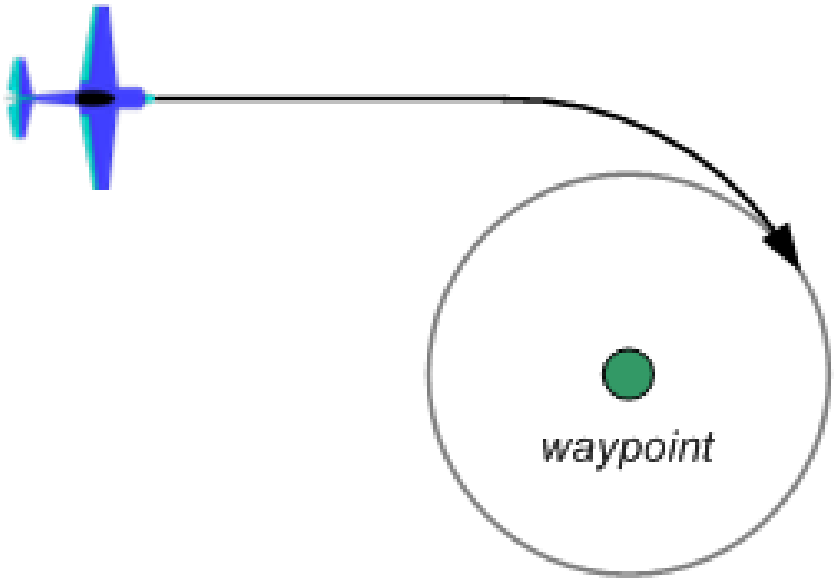
Networked System to be demonstrated



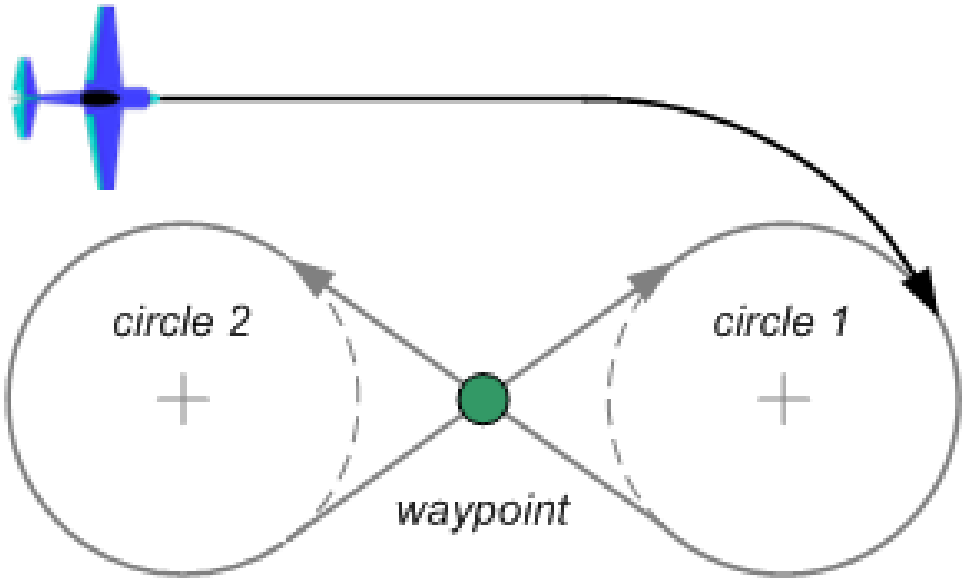
Flight Plan



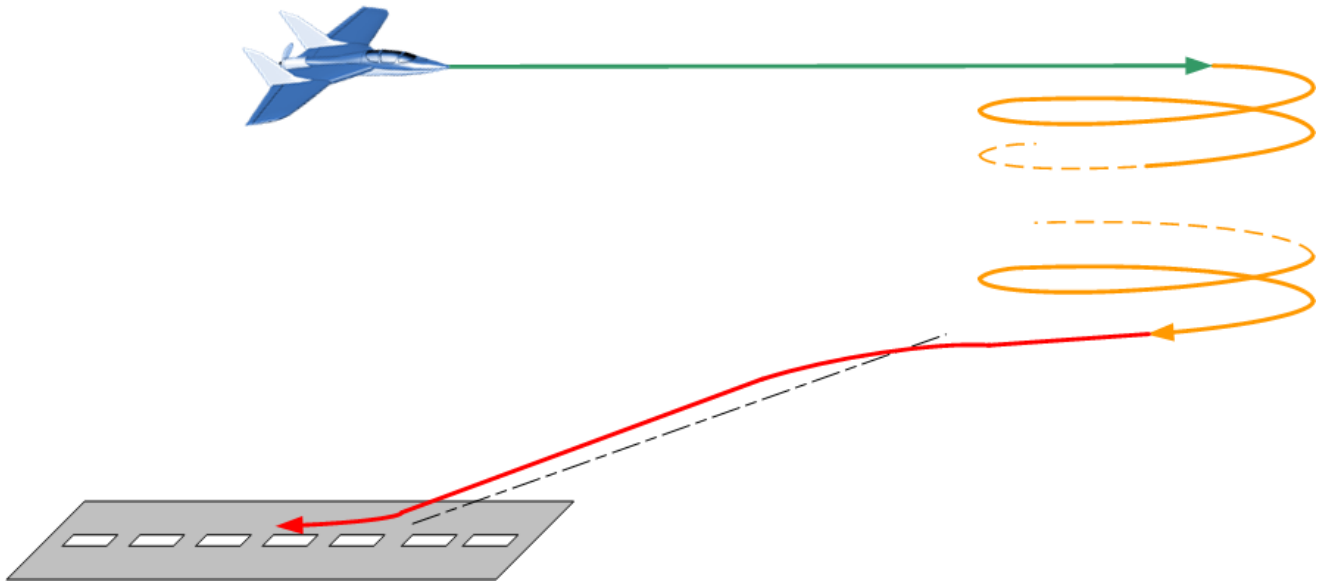
Flight Plan



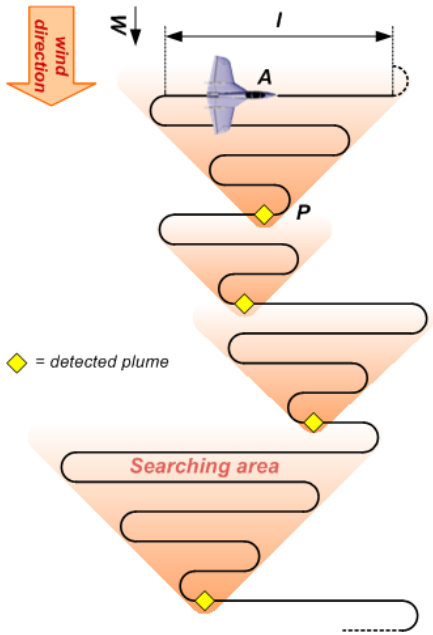
Flight Plan



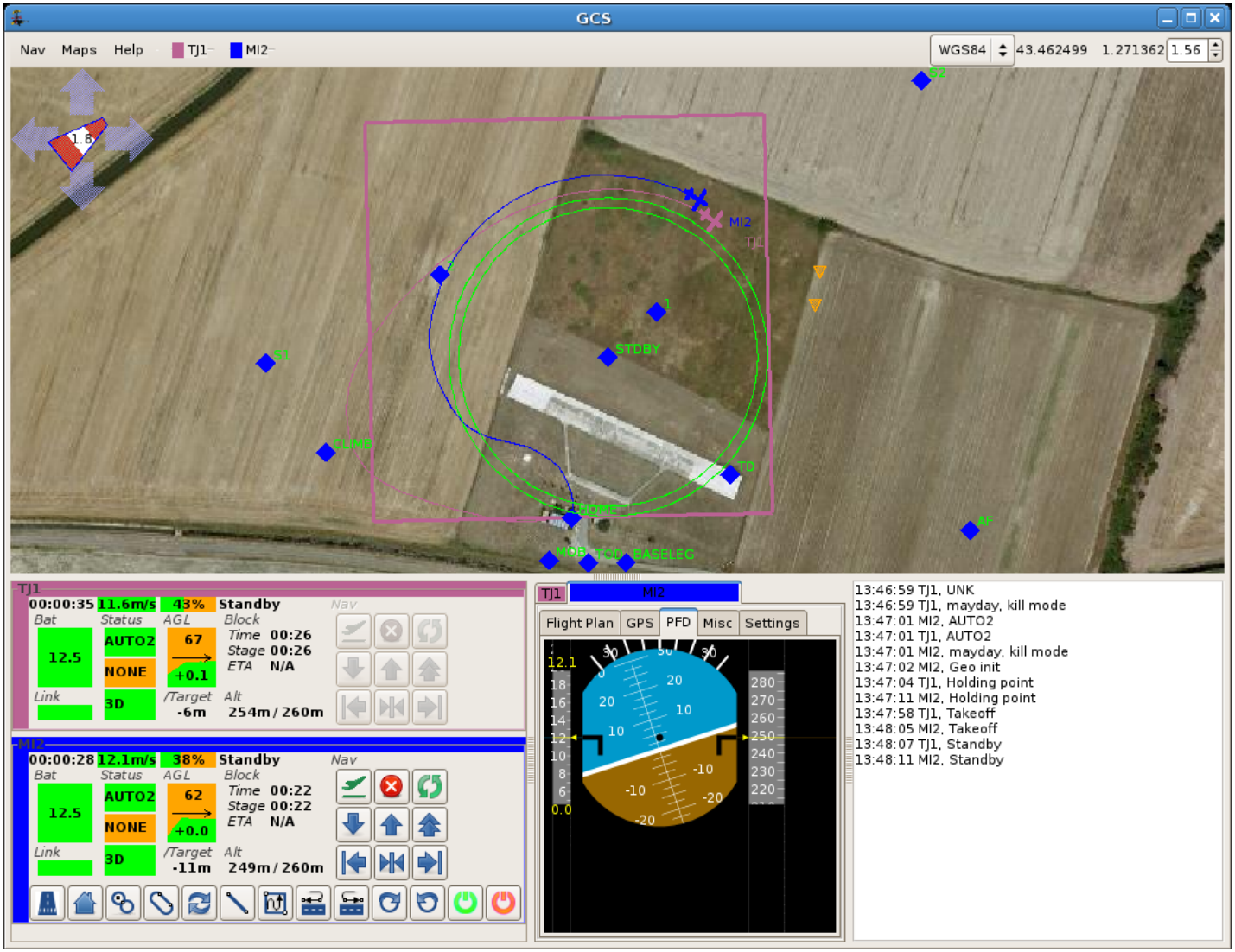
Flight Plan



Flight Plan



Ground control station

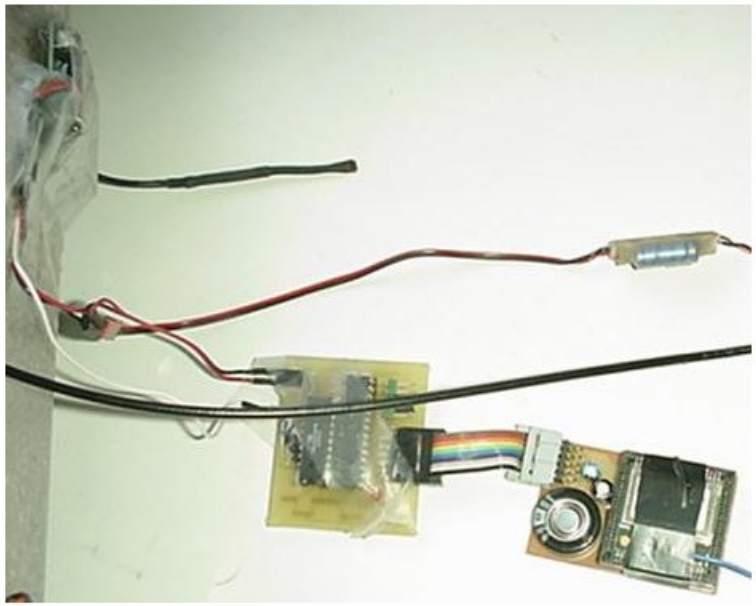


Video

Let's Fly

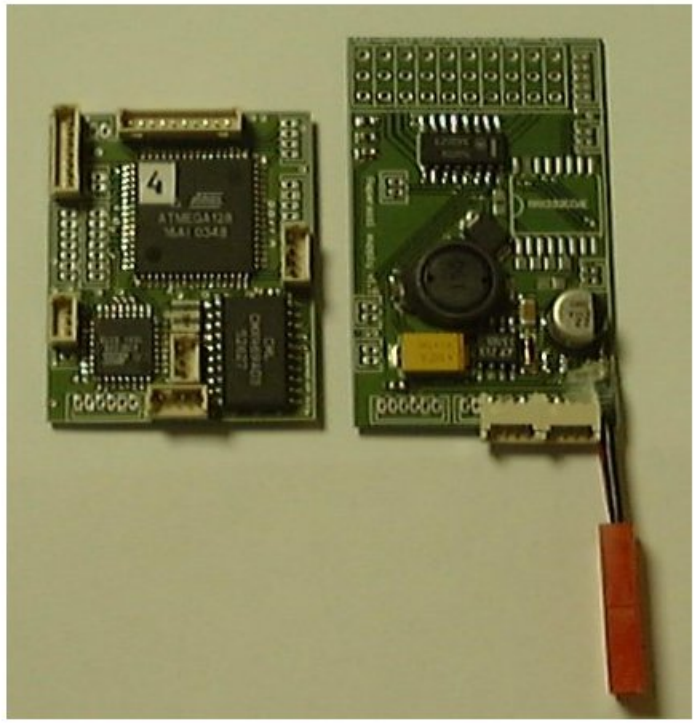
History

2003



History

2004



History

2005

History

2006

History

2007

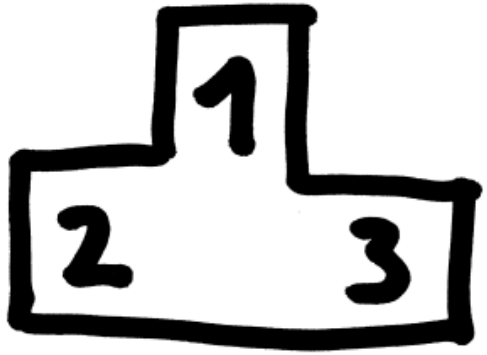
Goals

affordable

small

simple

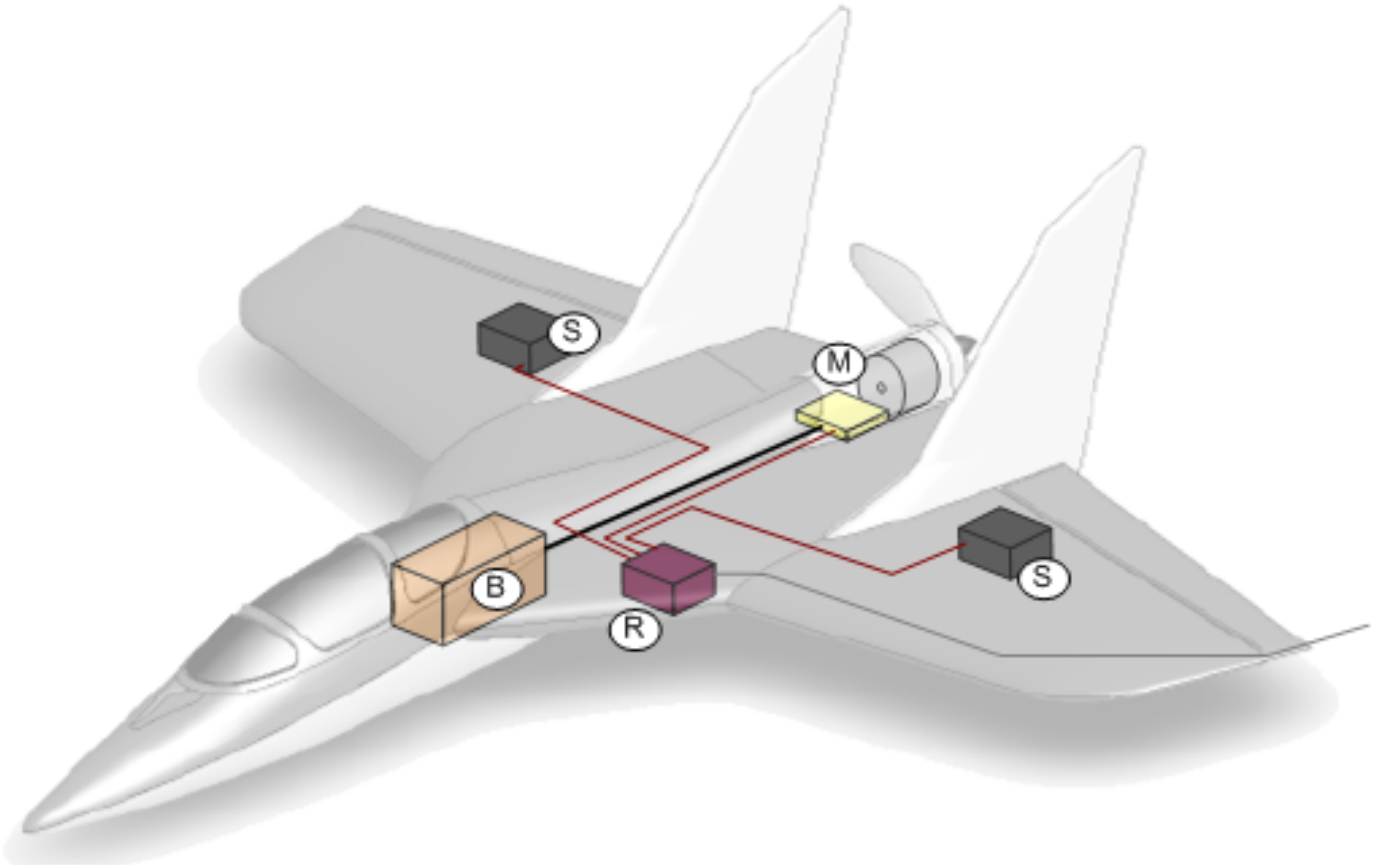
buildable



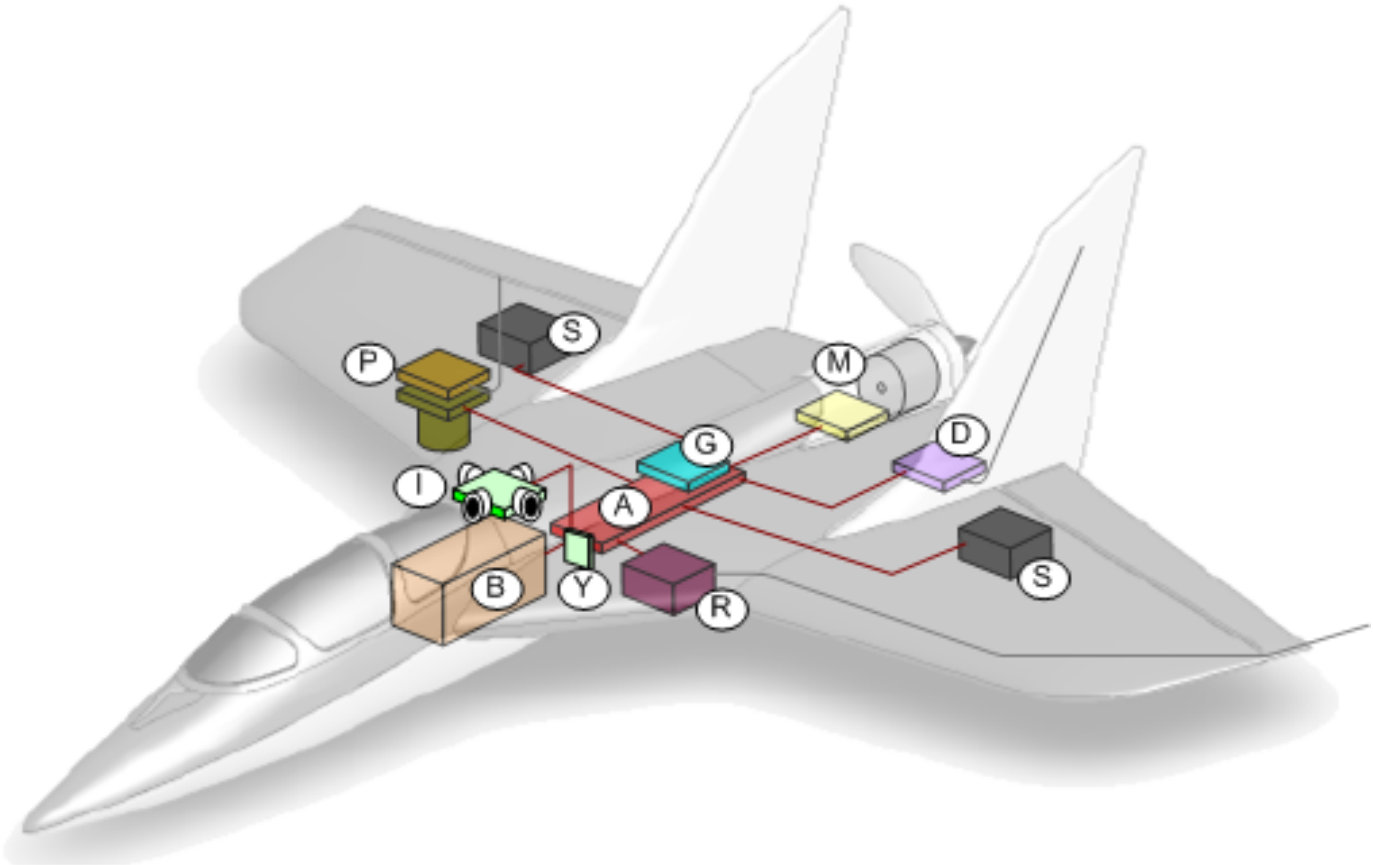
competitions

COTS

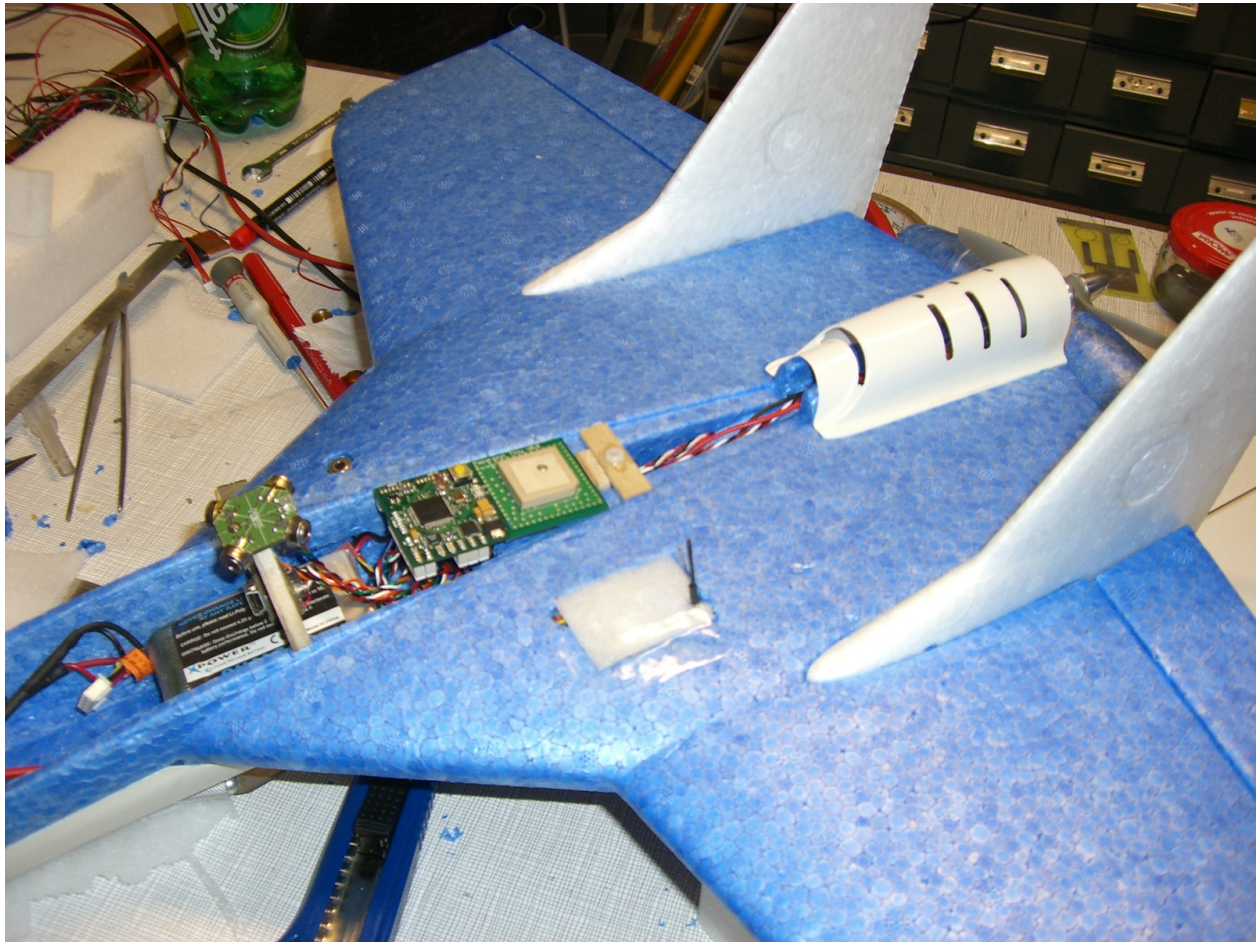
RC Toy vs UAV



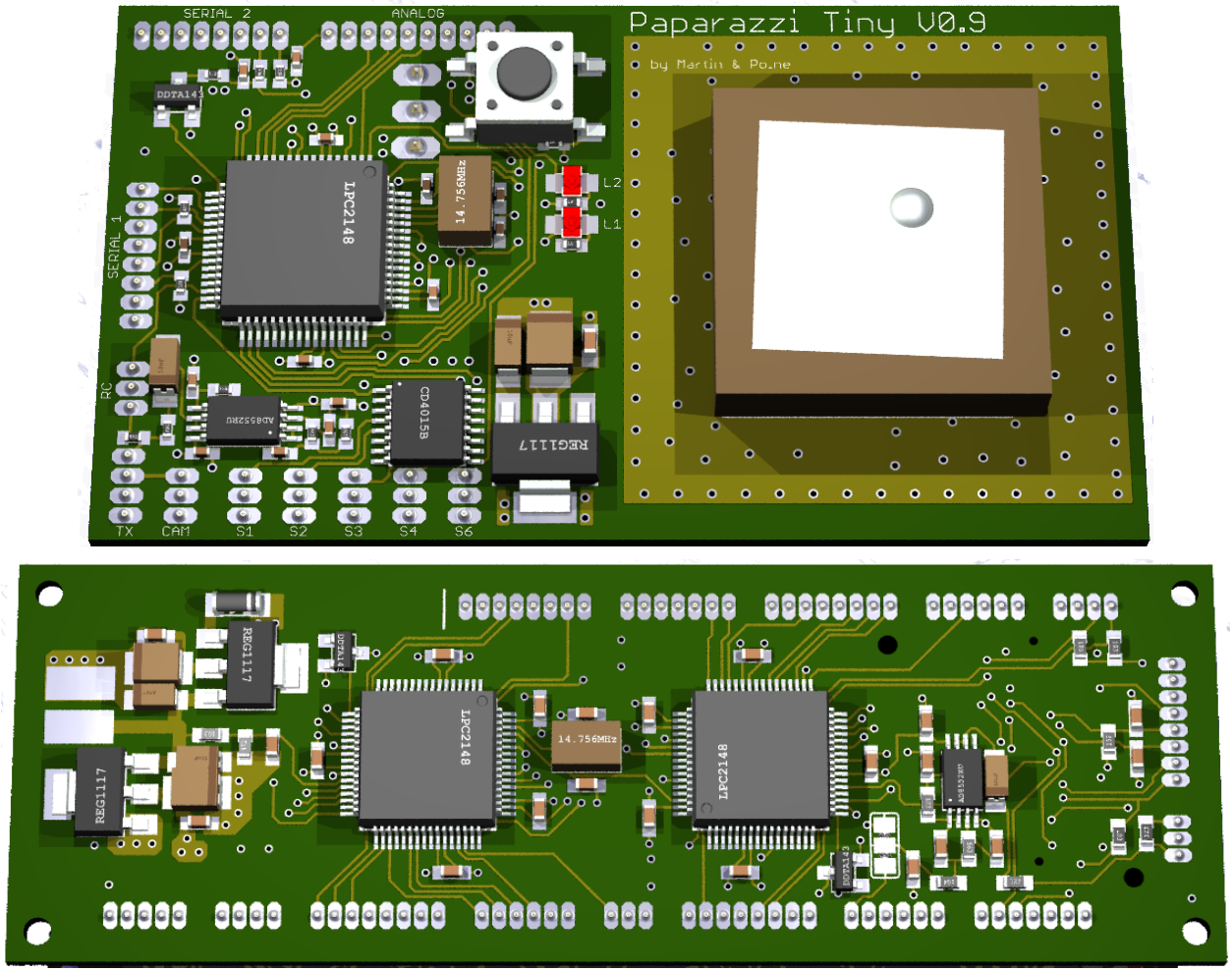
RC Toy vs UAV



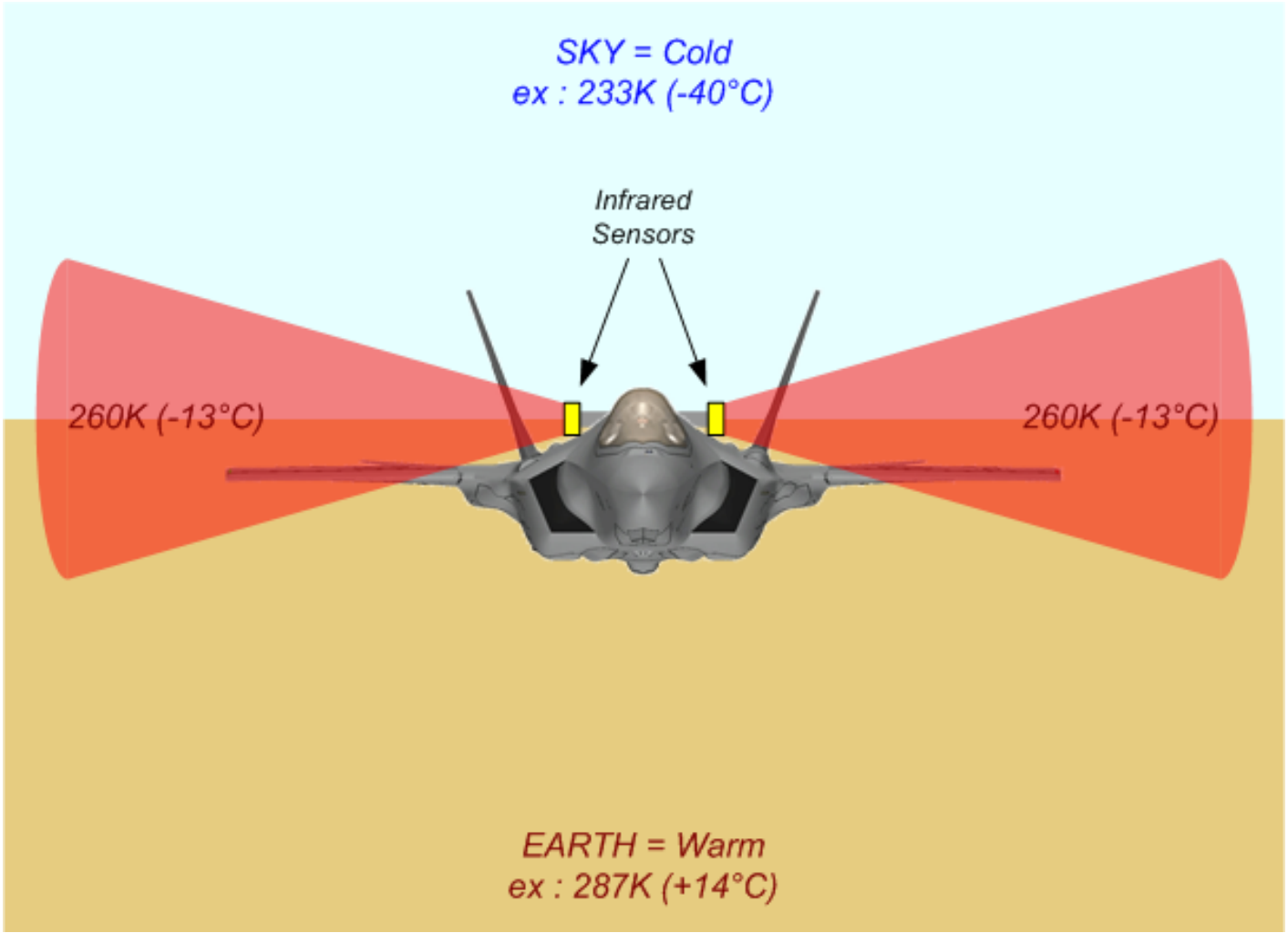
RC Toy vs UAV



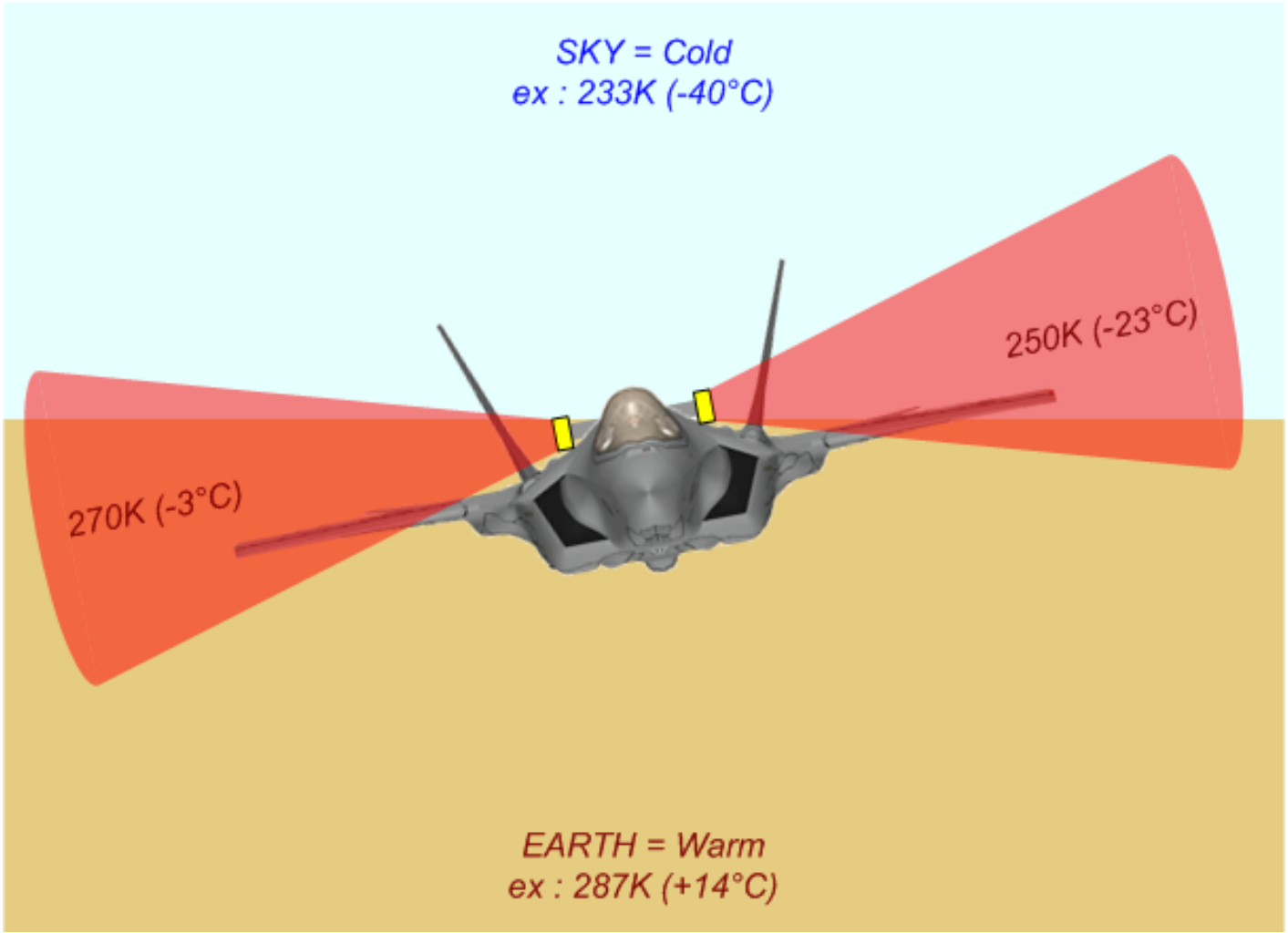
Controller board



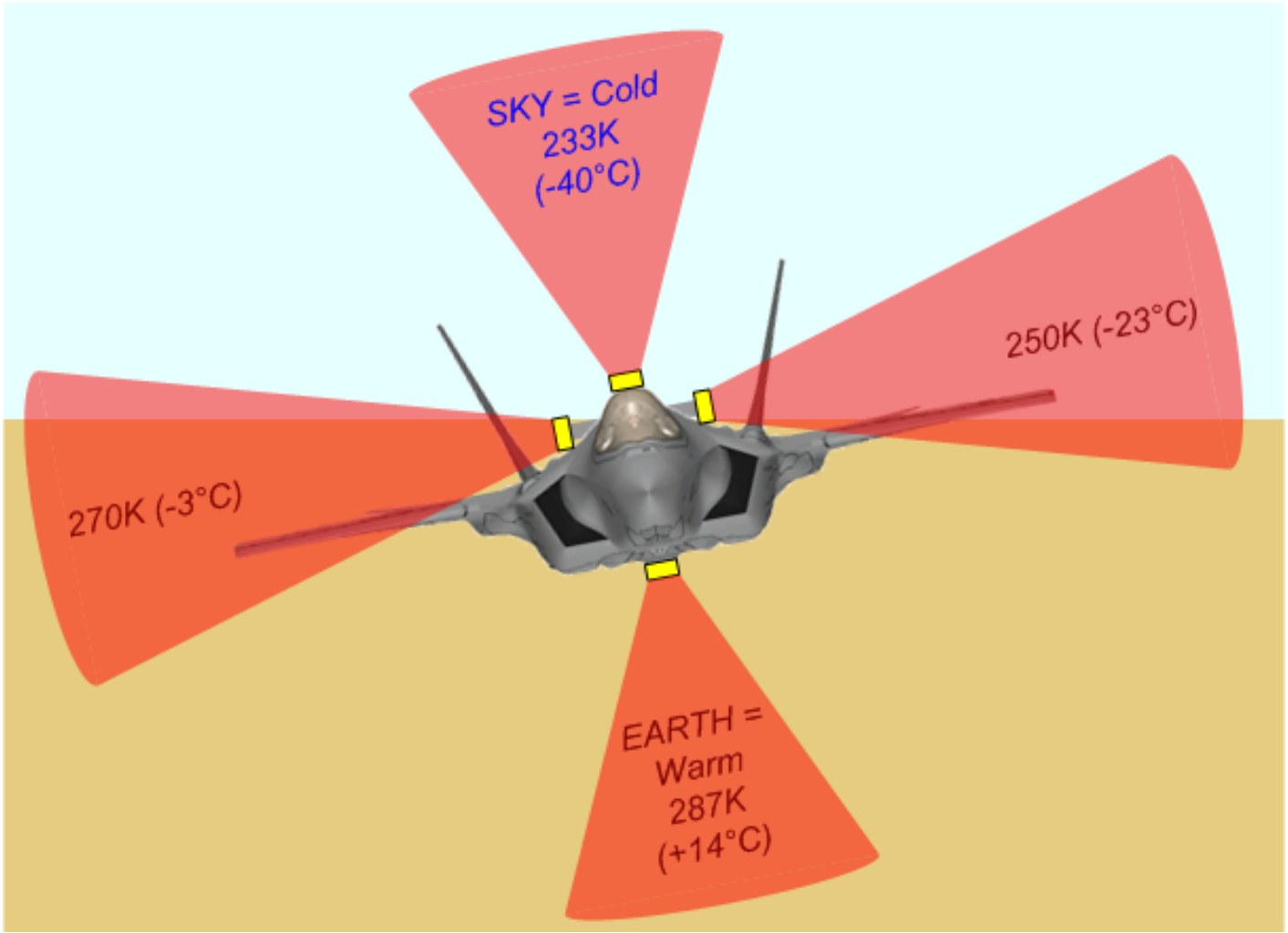
Infrared Attitude Measurement



Infrared Attitude Measurement



Infrared Attitude Measurement

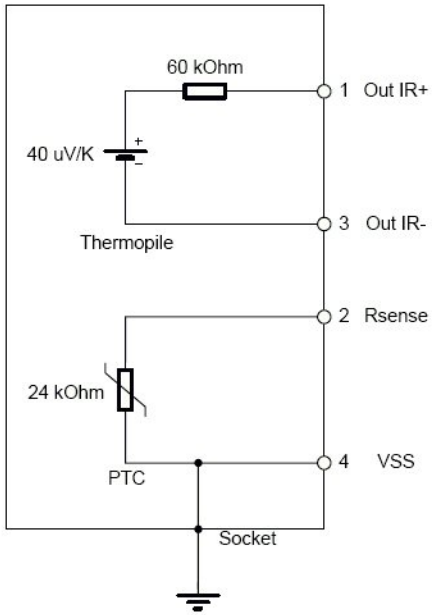


Infrared Thermopile

MLX90247 Thermopile

- Output voltage proportional to radiating temperature of seen body
- Sensitivity 40uV/C
- 90°cone of vision
- €10 in small quantities

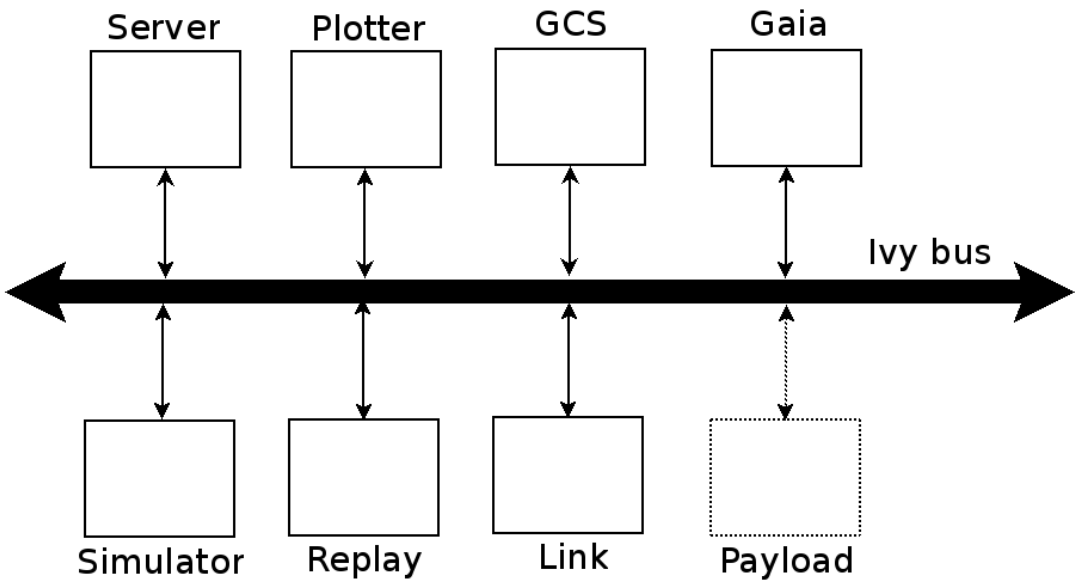
Used for example in car air conditioning system, non contact thermometers



GPS

Datalink

Networked Architecture



Onboard Software

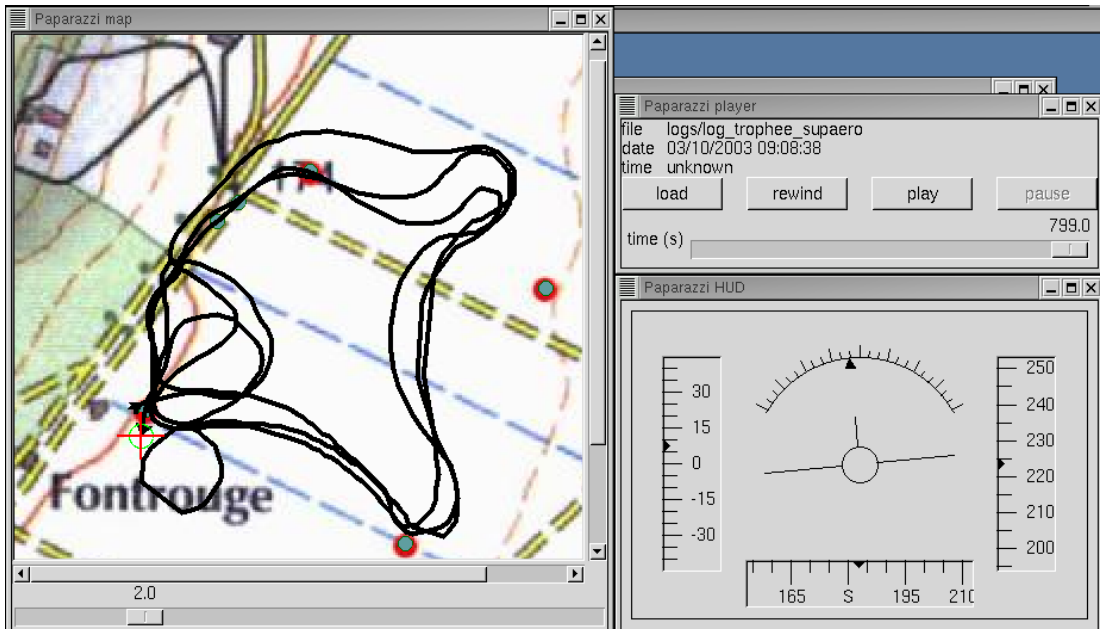
- Processor Architecture Independant
  avr, arm7 and i386
- Board Configuration Independant
  single and twin processors boards
- Vehicle Configuration Independant
  fixed wings and rotorcrafts
- Safe
  formal methods, real time analysis, extensive testing
- Efficient
  Code generation, compile time approach

Flight Plan Language

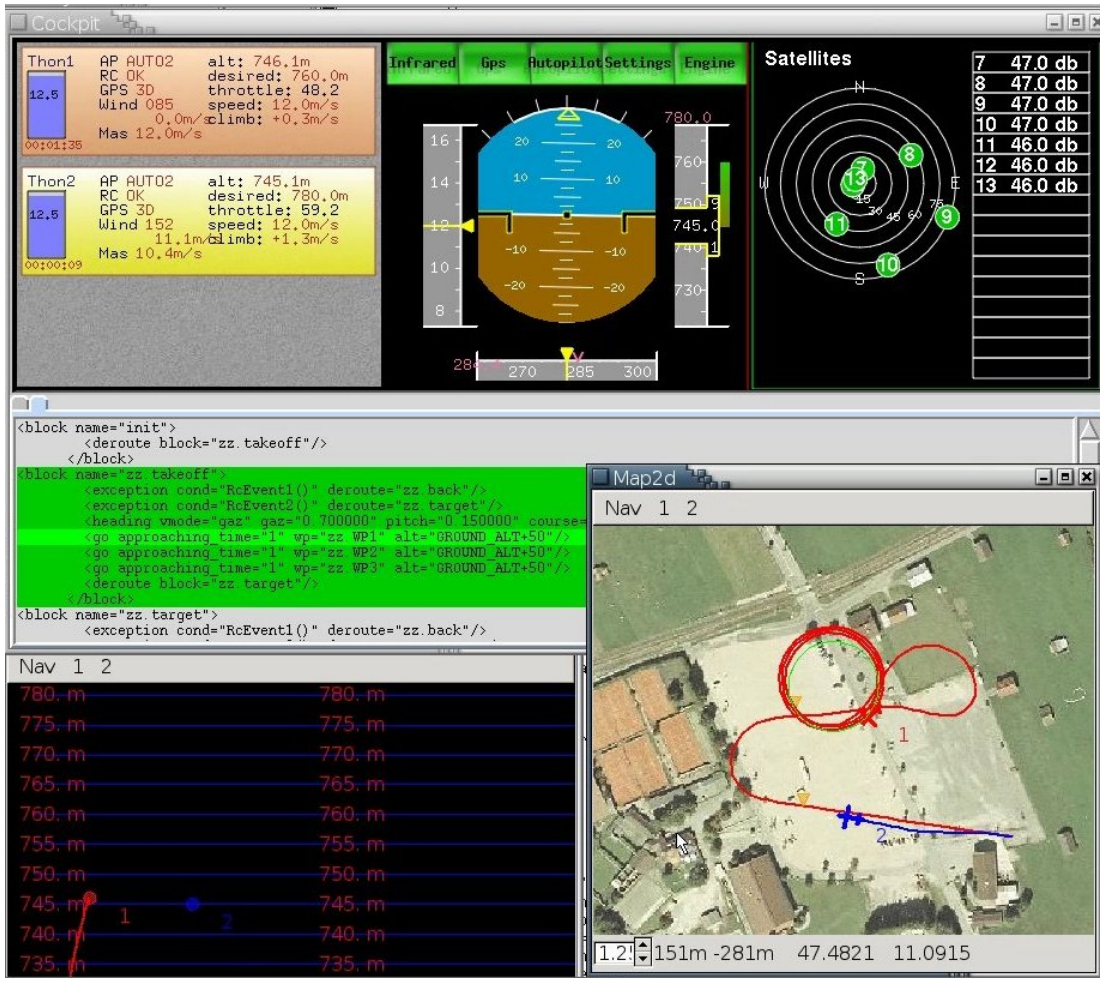
```
<flight_plan alt="75" ground_alt="0" lat0="43.46223" lon0="1.27289" max_dist_from_home="1500" name="turing complete">

  <waypoints>
    <waypoint name="HOME"  x="0"    y="0"/>
    <waypoint name="STDBY" x="9.4"  y="162.3"/>
    <waypoint name="2"     x="23.7" y="123.1"/>
  </waypoints>

  <exceptions>
    <exception cond="estimator_z > 300"  deroute="wait"/>
  </exceptions>

  <blocks>
    <block name="start">
      <go wp="STDBY"/>
    </block>

    <block name="circles">
      <for from="1" to="5" var="i">
        <set value="$i*750*cos(RadOfDeg(30))" var="waypoints[WP_2].x"/>
        <set value="$i*750*sin(RadOfDeg(30))+nav_radius" var="waypoints[WP_2].y"/>
        <go hmode="route" wp="2"/>
        <set value="$i*750*sin(RadOfDeg(30))" var="waypoints[WP_2].y"/>
        <circle radius="nav_radius" until="NavCircleCount()>1" wp="2"/>
      </for>
    </block>

    <block name="wait">
      <circle radius="nav_radius" wp="STBY"/>
    </block>
  </blocks>
</flight_plan>
```

Ergonomy

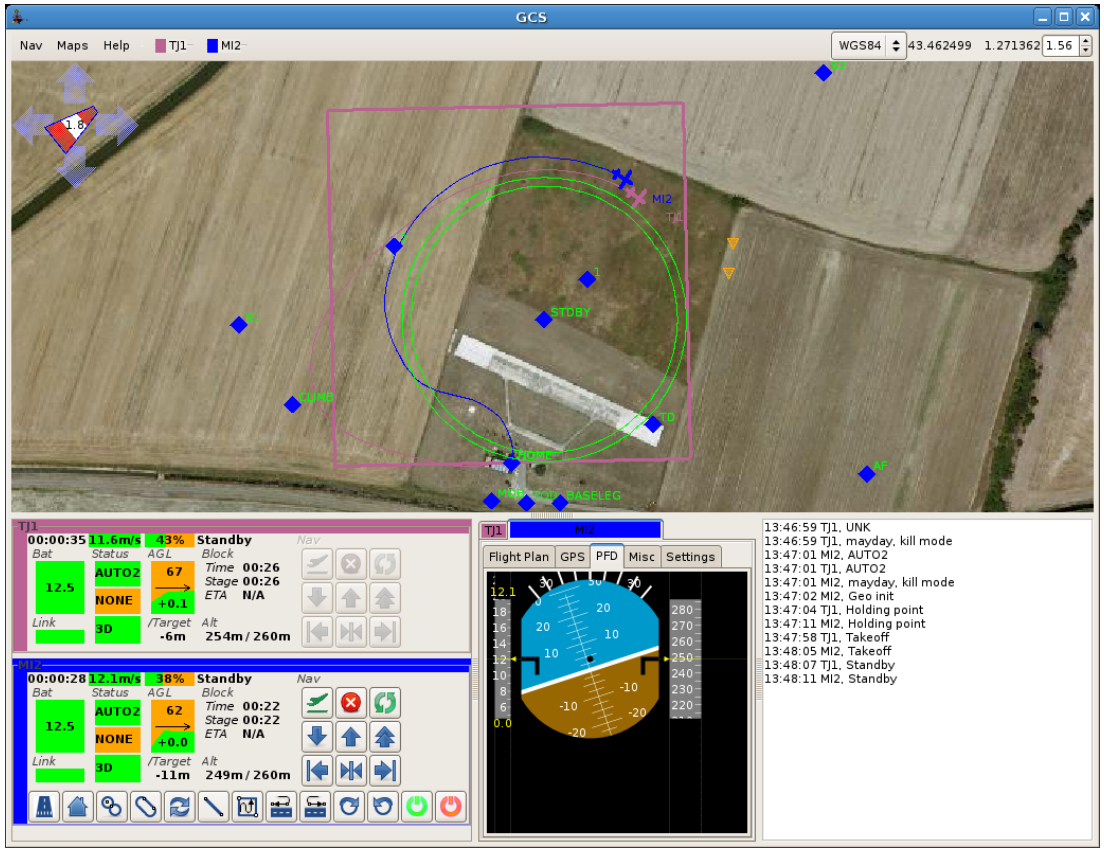
Ergonomy


Paparazzi map
Fontrouge
2.0
Paparazzi player
file logs/log_trophee_supaero
date 03/10/2003 09:08:38
time unknown
load
rewind
play
pause
799.0
time (s)
Paparazzi HUD
30
15
0
-15
-30
250
240
230
220
210
200
165
S
195

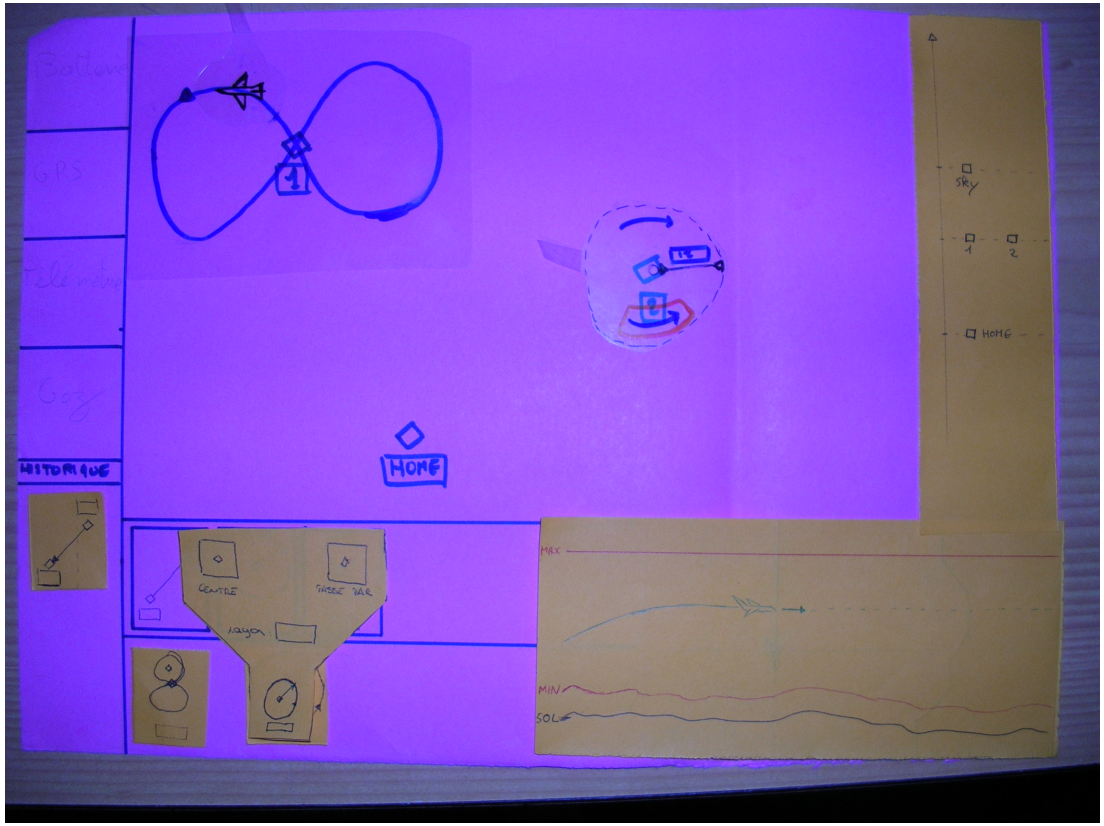
Ergonomy


Cockpit
Thon1
AP AUTO2
RC OK
GPS 3D
Wind 085
Mas 12.0m/s
alt: 746.1m
desired: 760.0m
throttle: 48.2
speed: 12.0m/s
climb: +0.3m/s
Thon2
AP AUTO2
RC OK
GPS 3D
Wind 152
Mas 10.4m/s
alt: 745.1m
desired: 780.0m
throttle: 59.2
speed: 12.0m/s
climb: +1.3m/s
Infrared
Gps
Autopilot
Settings
Engine
Satellites
7 47.0 db
8 47.0 db
9 47.0 db
10 47.0 db
11 46.0 db
12 46.0 db
13 46.0 db
<block name="init">
<deroute block="zz_takeoff"/>
</block>
<block name="zz_takeoff">
<exception cond="RcEvent1()" deroute="zz_back"/>
<exception cond="RcEvent2()" deroute="zz_target"/>
<go approaching_time="1" wp="zz_WP1" alt="GROUND_ALT+50"/>
<go approaching_time="1" wp="zz_WP2" alt="GROUND_ALT+50"/>
<go approaching_time="1" wp="zz_WP3" alt="GROUND_ALT+50"/>
<deroute block="zz_target"/>
</block>
<block name="zz_target">
<exception cond="RcEvent1()" deroute="zz_back"/>
Nav 1 2
Map2d
Nav 1 2
151m -281m 47.4821 11.0915

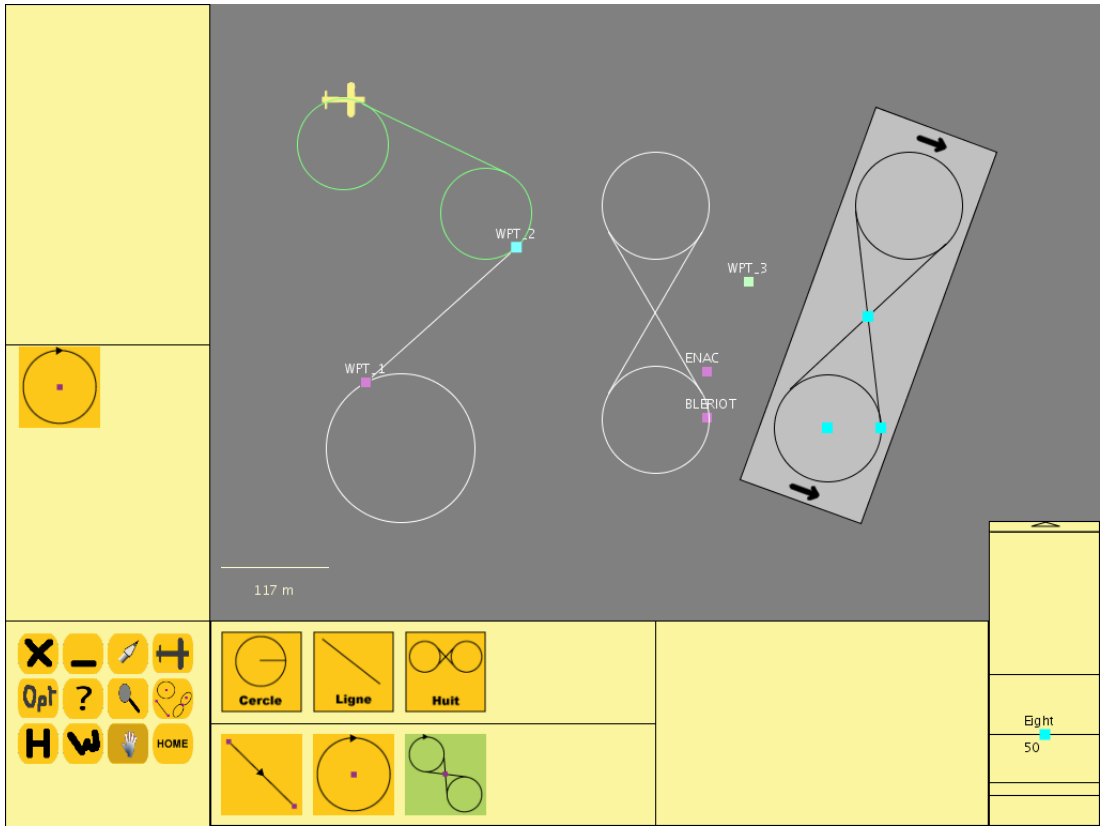
Ergonomy


GCS
Nav Maps Help TJ1 MI2
WGS84 43.462499 1.271362 1.56
TJ1
00:00:35 11.6m/s 43% Standby
Bat Status AGL Block
12.5 AUTO2 67 Time 00:26
NONE +0.1 Stage 00:26
Link 3D /Target -6m Alt 254m / 260m ETA N/A
MI2
00:00:28 12.1m/s 38% Standby
Bat Status AGL Block
12.5 AUTO2 62 Time 00:22
NONE +0.0 Stage 00:22
Link 3D /Target -11m Alt 249m / 260m ETA N/A
Flight Plan GPS PFD Misc Settings
13:46:59 TJ1, UNK
13:46:59 TJ1, mayday, kill mode
13:47:01 MI2, AUTO2
13:47:01 TJ1, AUTO2
13:47:01 MI2, mayday, kill mode
13:47:02 MI2, Geo init
13:47:04 TJ1, Holding point
13:47:11 MI2, Holding point
13:47:58 TJ1, Takeoff
13:48:05 MI2, Takeoff
13:48:07 TJ1, Standby
13:48:11 MI2, Standby

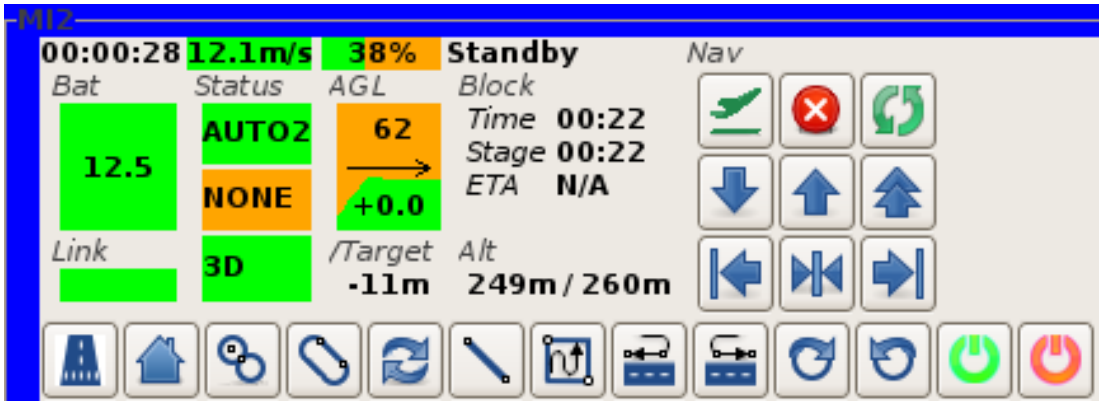
Ergonomy



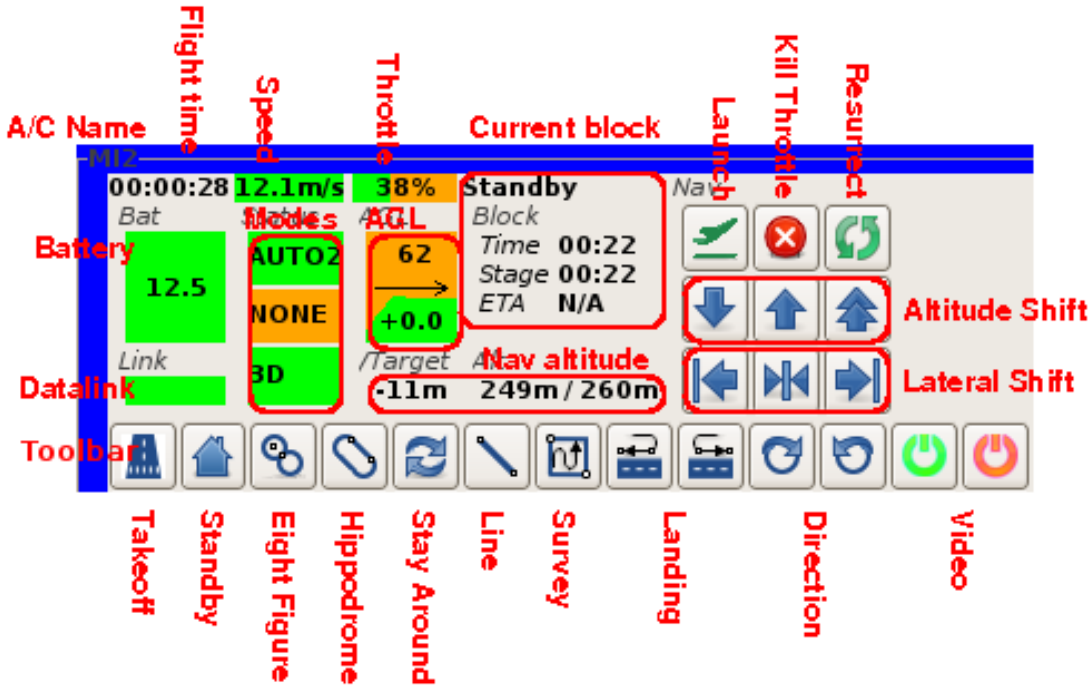
Ergonomy


WPT_2
WPT_3
WPT_1
ENAC
BLERIOT
117 m
Cercle
Ligne
Huit
HOME
Eight
50

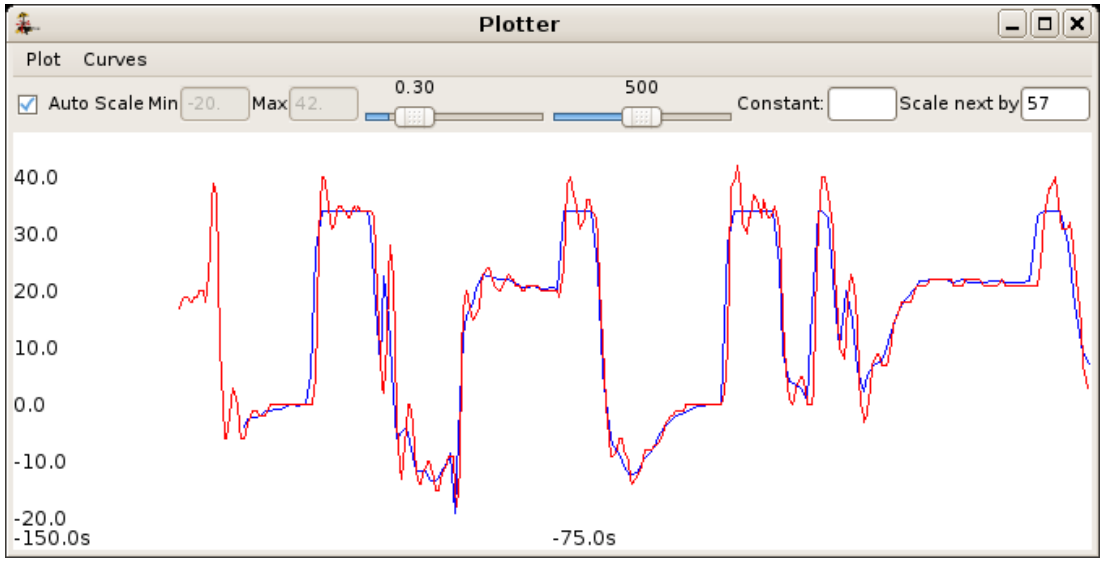
Ergonomy


MIZ
00:00:28
12.1m/s
38%
Standby
Nav
Bat
Status
AGL
Block
12.5
AUTO2
NONE
62
+0.0
Time 00:22
Stage 00:22
ETA N/A
Link
3D
/Target
-11m
Alt
249m / 260m

Ergonomy


A/C Name
Flight time
Speed
Throttle
Current block
Launch
Kill Throttle
Resurrect
Battery
Datalink
Toolbar
Altitude Shift
Lateral Shift
00:00:28
12.1m/s
38%
Standby
Block
Time 00:22
Stage 00:22
ETA N/A
Bat
Modes
AGL
AUTO2
NONE
3D
62
+0.0
12.5
Link
/Target
Nav altitude
-11m
249m / 260m
Takeoff
Standby
Eight Figure
Hippodrome
Stay Around
Line
Survey
Landing
Direction
Video

Flight Data Analysis



Flight Data Analysis

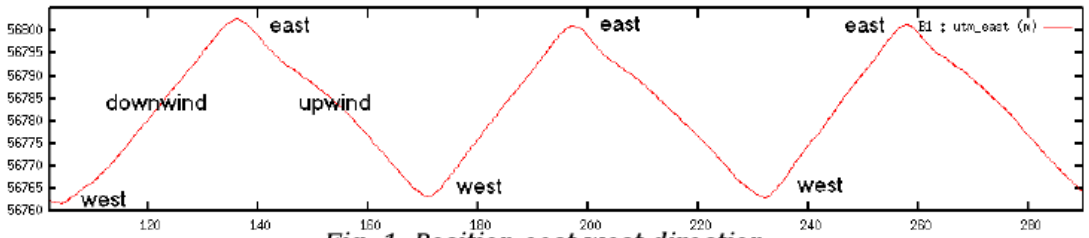


Fig. 1: Position east-west direction

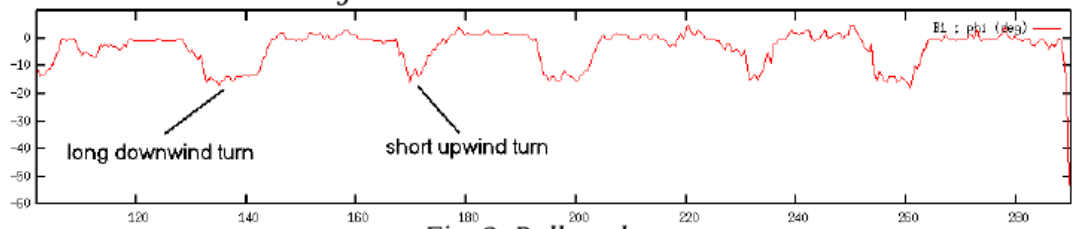


Fig. 2: Roll angle

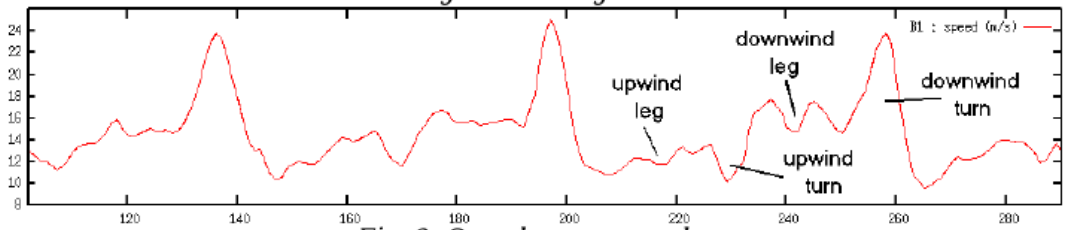
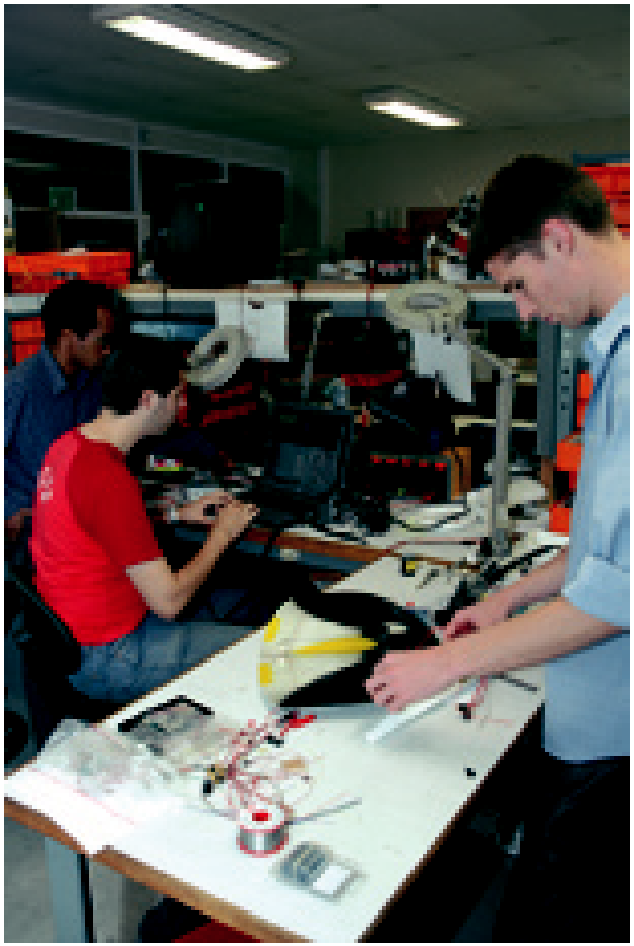


Fig. 3: Speed over ground

MAV Competitions

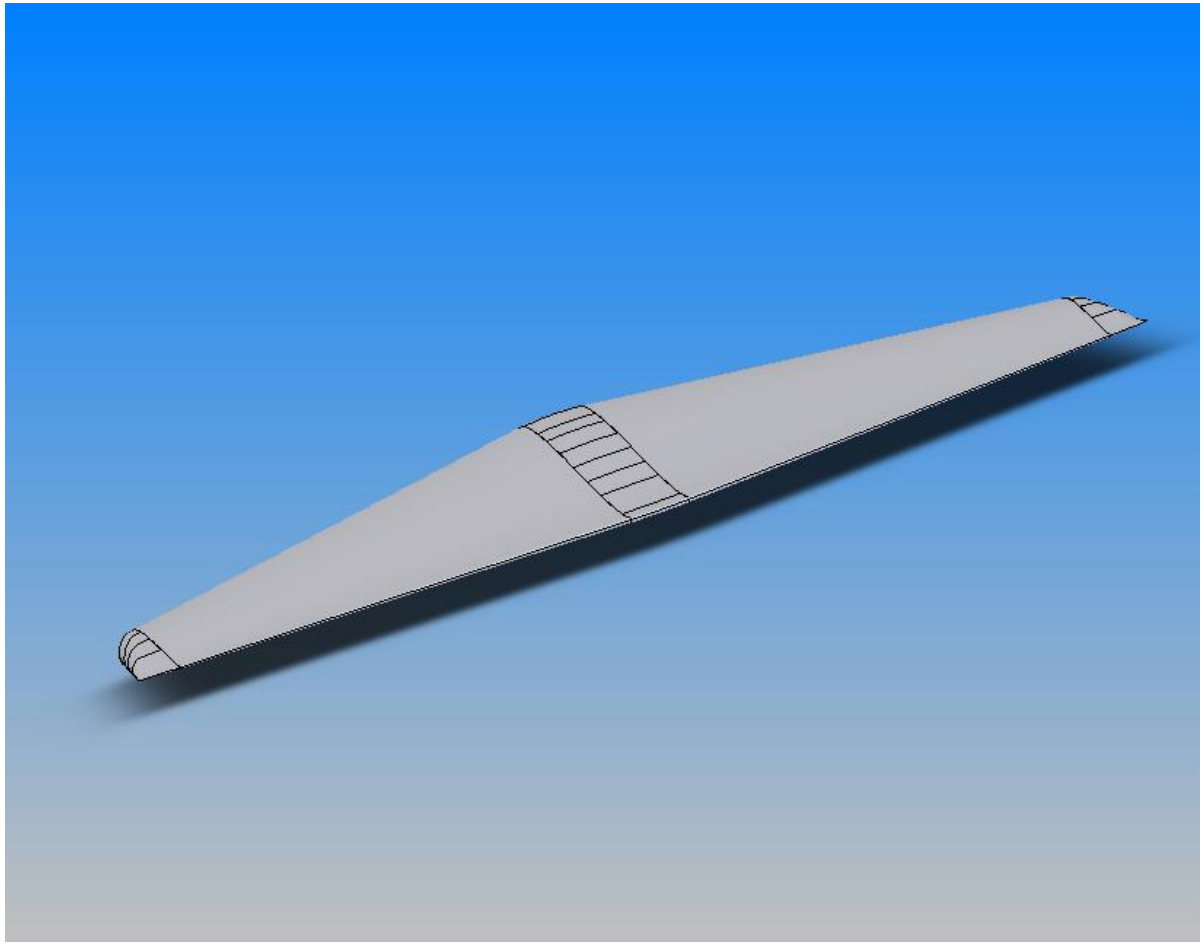
- JMD03, Toulouse, France : 1st place with the Twinstar
- EMAV04, Braunschweig, Germany : 1st place with the Microjet
- JMD04, Toulouse, France : 1st place with the Microjet
- MAV05, Garmisch, Germany : 4 Paparazzi teams at the first 4 places
- EMAV06, Braunschweig, Germany : all the teams were equiped with Paparazzi
- MAV06, Sandestin, Florida : 2nd and 3rd places
- MAV07, Toulouse, France : 1st place (tie), 3rd, 4th and 5th places

Teaching



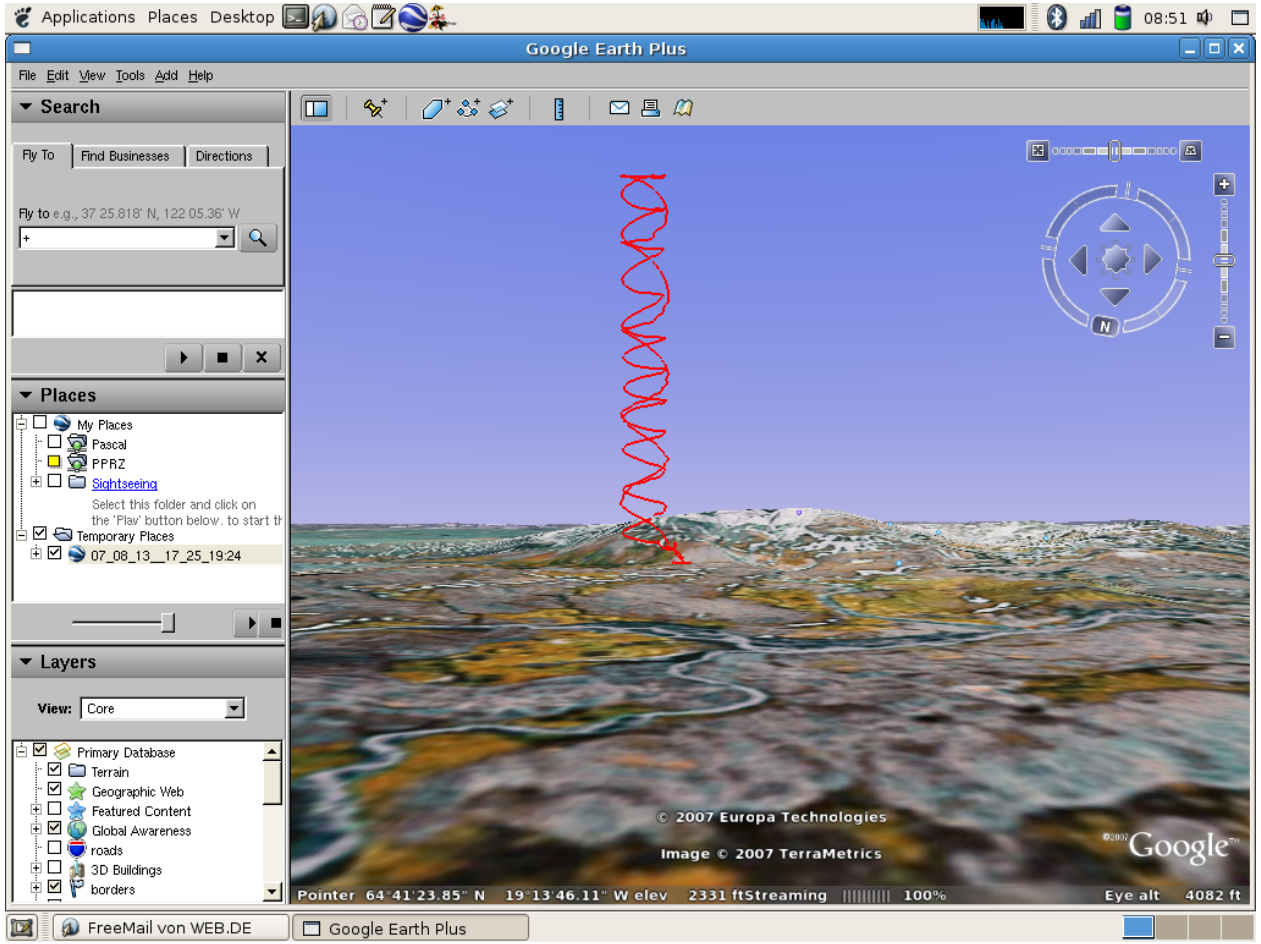
- U. of Arizona
- HS Bremen
- Istanbul TU
- U. of Sheffield
- U. de Sherbrooke
- Supaero

Aeronautics/UAV research



Other research

Other research



Operational applications

Conclusions

- Technology is ready
- Wide fields of applications
- Reglementation is lagged (RC / segregated airspace)
- Integration to civil traffic

Acknowledgements

- Pascal Brisset

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- Murat Bronz

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- Michel Gorraz

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- Arnold Schröter

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- Arnold Schröter
- Jeremy Tyler

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- Michel Gorraz
- Anton Kochevar
- Christian Lindenberg
- Arnold Schröter
- Jeremy Tyler
- and all others...

Further Informations

- http://paparazzi.nongnu.org
- http://paparazzi.enac.fr
- irc://irc.freenode.net/#paparazzi

Questions