Development Of Computational Tools For Analysis And Evaluation Of Autonomous Parafoil Systems

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Outline

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- Introduction
- Aerodynamic model
- Structural model
- Coupling procedure
- 6-DoF Simulation model
- Trajectory example
- Conclusions

CIMNE: Fact and Figure

CIMNE is a consortium of Generalitat de Catalunya and UPC founded in 1987.

Today is a recognized institution with a growing international presence and strong experience in several research areas with a professional staff of researches.

CIMNE offer upstream research capabilities, transfer technology competence, industrial innovation partnerships and customized investigation programs.

Following are some figure:

STAFF:	up to 200 people (150 researchers)
PROJECTS:	up to 100 ongoing projects (EU, national, regional and international and industrial cooperation agreements)
PUBLICATIONS:	101 books, 156 technical reports, up to 800 scientific works.
CONGRESS:	up to 80 national and international congresses
TRAINING:	up to 370 course and seminars
LOCATIONS:	Barcelona, Madrid, Castelldefels, Terrassa, Washington, Singapore

CIMNE-BARCELONA

CIMNE-CASTELLDEFELS

CIMNE-TERRASSA

Parachute simulation at CIMNE: Antecedents

- The role of parachutes in many civil, humanitarian and military applications call for new and improved computational tools to meet the current need of software applications in the field.

- The development of simulation tools for the analysis of parachute systems begins in 2005 at CIMNE in cooperation with **CIMSA Ingeniería en Sistemas**, a leading parachute designer and manufacturer (www.cimsa.com).

- Initial joint efforts developed **PARACIMSA**, a simulation code for coupled aerodynamic-structural analysis of ram-air parachutes. Its main features are:
  - **Stationary** low-order panel method + **implicit** finite element based code for membranes and cables.
  - Capabilities: prediction of **stationary aerodynamic characteristics.** Simulation of maneuvers and reefing. Simplified parachute inflation model.

Latest advances in parachute simulation

- Relaying on PARACIMSA experience, a new analysis code named **PARACHUTES** was recently developed in order to accomplish **transient coupled analysis** while improving modularity, expandability, robustness and computational efficiency.

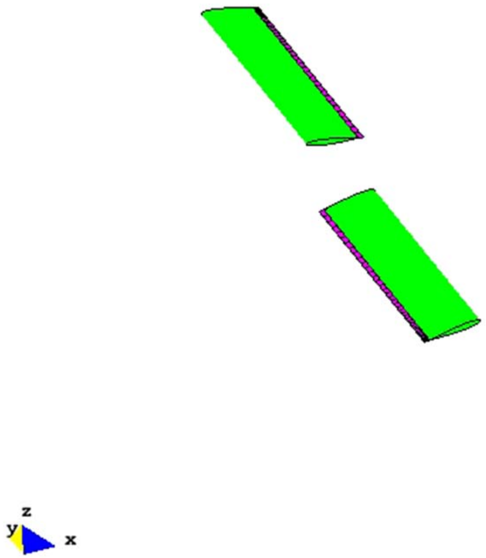
- The aerodynamic model is based on an **unsteady low-order panel method**. The structural solver is a **dynamic (explicit) finite element** based code. The new structural code also allows simulation of the complete parachute-payload system dynamics.

- A set of tools including a **6 DoF parachute flight simulator** (ParaSim6) was also developed for trajectory analysis and design of guidance, navigation and control systems (GNC) with minimum computational cost. The simulator is based on a **parametric model** (aerodynamic derivatives).

PARACHUTES: Aerodynamic model

- Unsteady three-dimensional potential flow model.
- Low-order panel method (constant-strength doublet and source panels)
- Body discretization → thick / thin surface boundaries, triangular / quadrilateral panels, structured / unstructured grids.
- Lifting and non-lifting bodies having solid or permeable surface boundaries (transpiration).
- Multiple body analysis.
- Time-marching wake model.
- Wind loads are applied to parachute suspension lines, which are considered long cylinders exposed to the wind.

Unsteady numerical applications



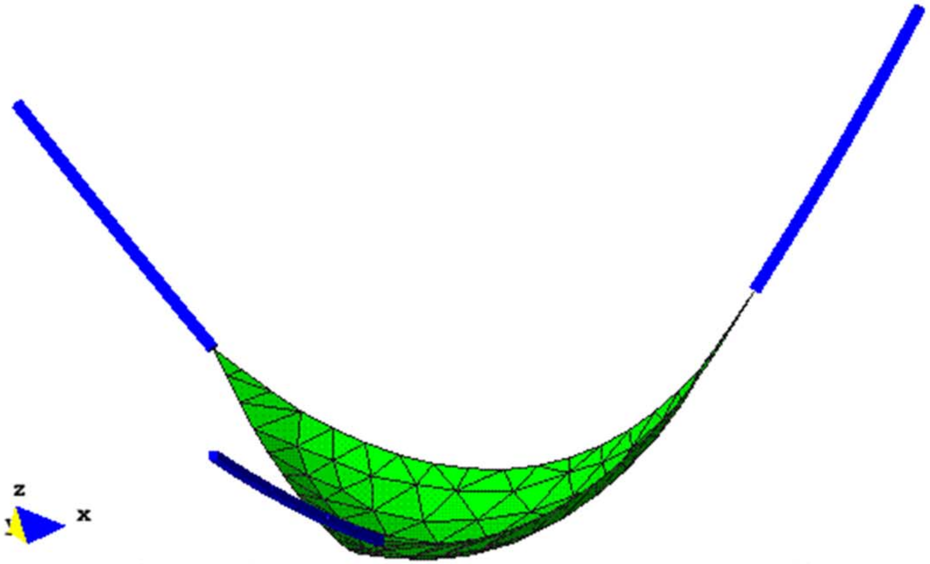
Impulsive starting wing

Hovering rotor (Ω=650 rpm)

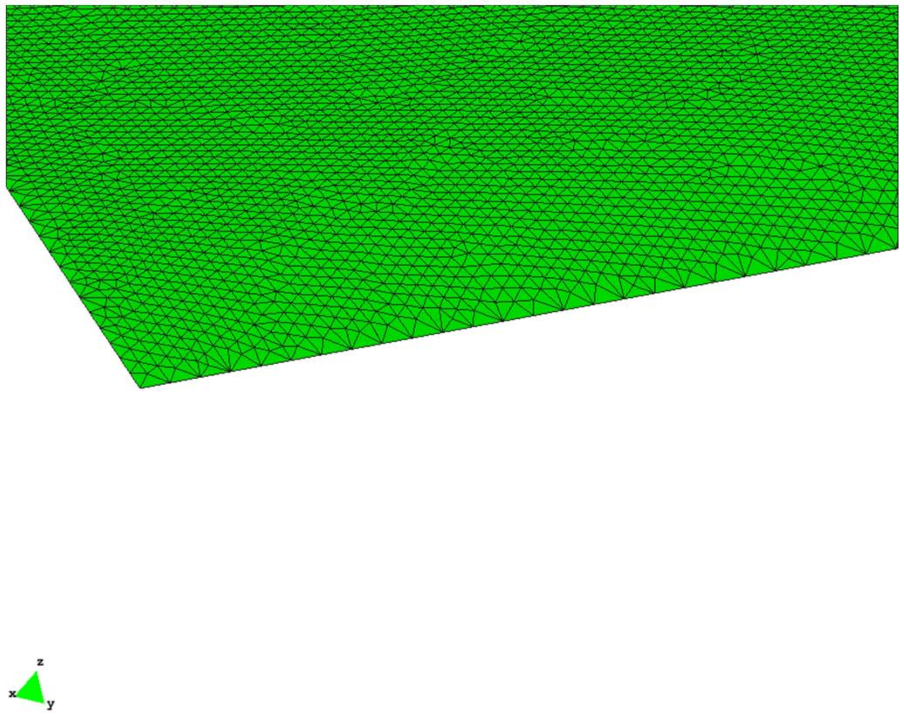
PARACHUTES: Structural model

- Explicit dynamic analysis:
  - ✓ No convergence issues in highly non-linear problems, e.g., large displacements and deformations, complex material behavior, etc.
  - ✓ Suitable for calculating transient (dynamic) as well as long-term (static) response.
  - ✓ Easily vectorized (efficient in parallel environments).
- Three-node linear membrane elements.
- Two-node linear cable elements.
- Includes wrinkling model.
- Rayleigh damping and bulk viscosity for noise control.

Large displacement & wrinkling capability

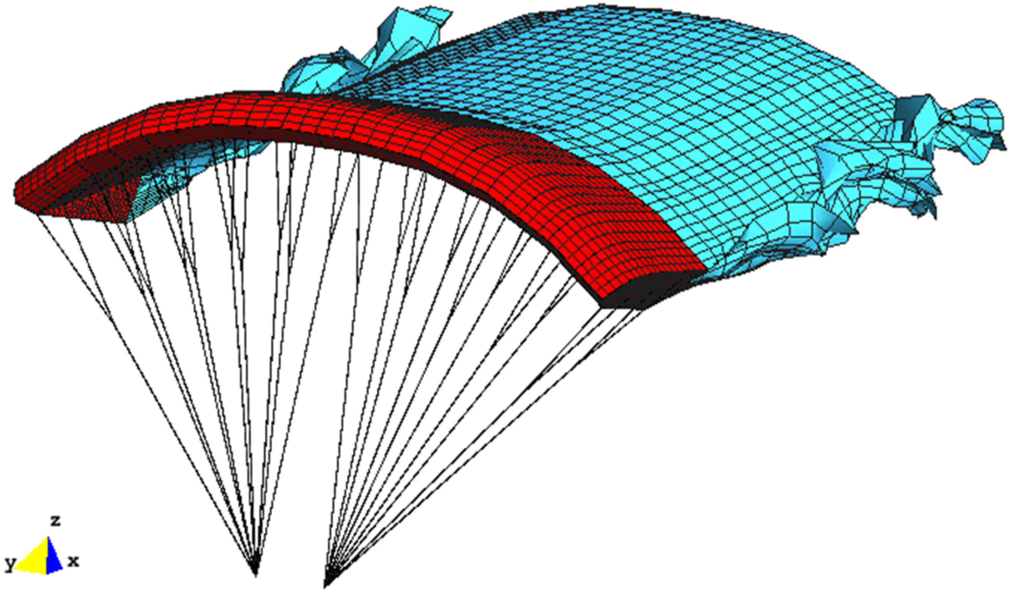


Deformation (x1): DISPLACEMENT of PUMI MEM, step 1.5541.

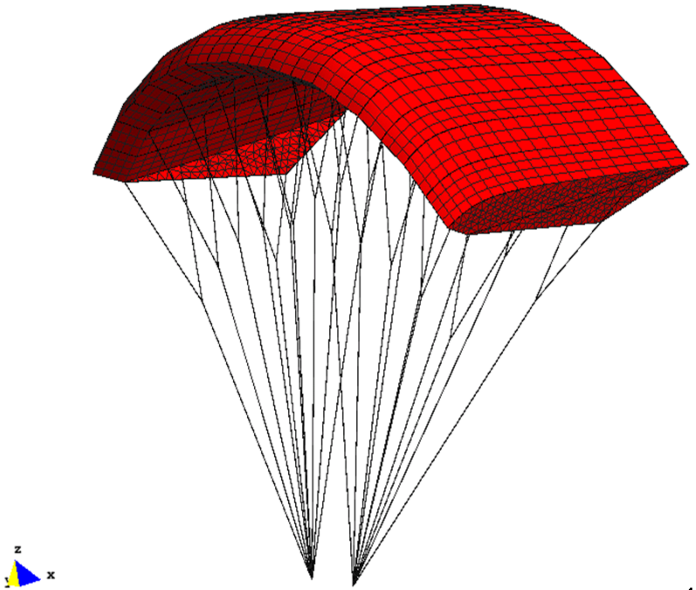


PARACHUTES: Coupling procedure

- A 2-way coupling between the aerodynamic (A) and structural (S) models is adopted.
- The A/S models share the same mesh. If quadrilateral elements are present, they are converted into triangles when solving the structure.
- As the stability limit of the structural solver is small, several structural iterations are performed for each aerodynamic time step.
- Convergence to the steady state regime can be accelerated by using an under-relaxation technique when transferring aerodynamic loads to the structure.
- For long-term response analysis (e.g. trajectory analysis) the number of structural steps can be reduced by approximating the behavior of the membrane as quasi-static (i.e. considering only discrete states of equilibrium along the flight path).



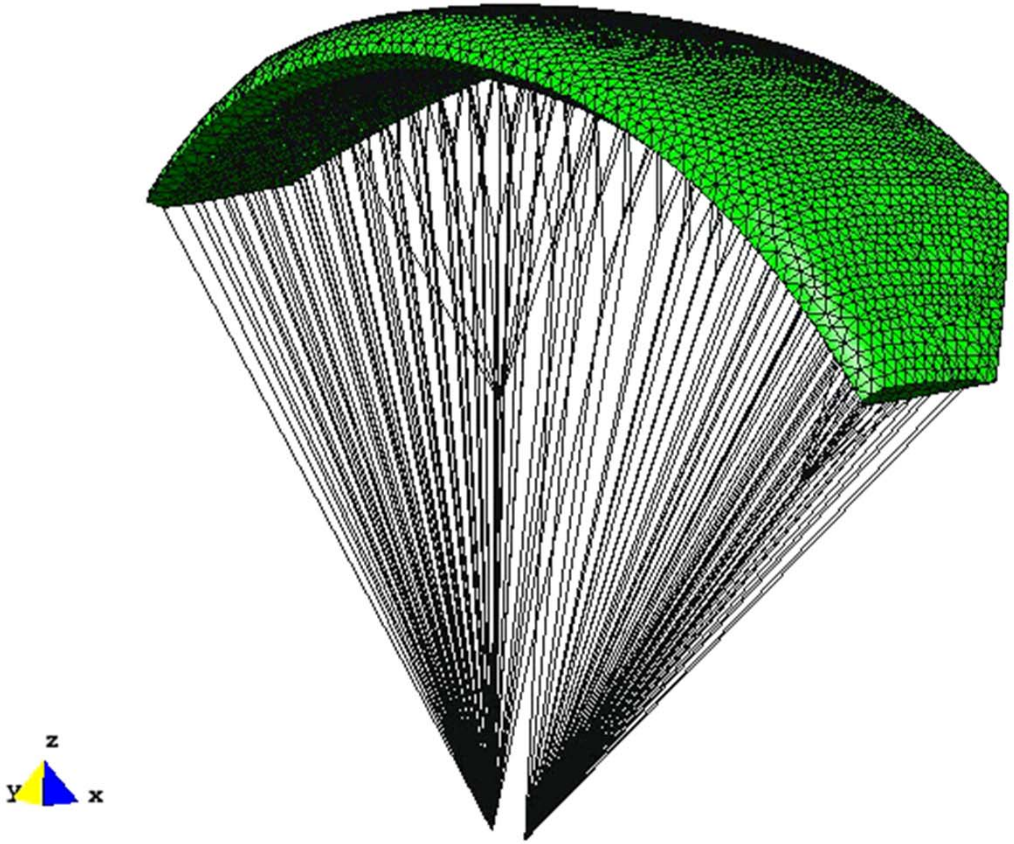
Dynamic structural behavior



Application example 1 - Fastwing

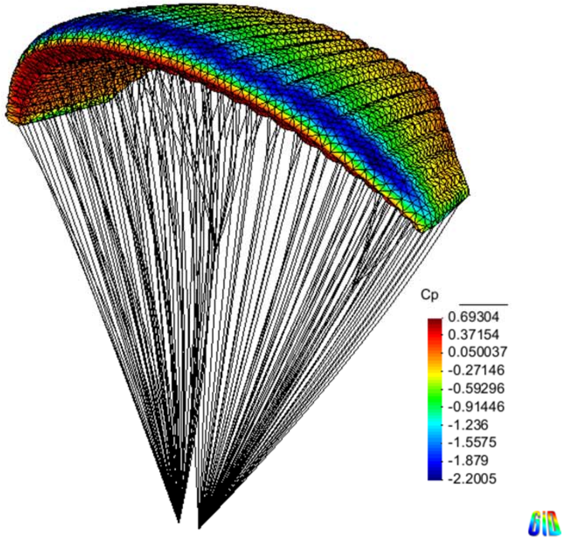
- Large ram-air parachute designed and manufactured by CIMSA within the FASTWing project framework.
- Target design: high wing loads and glide ratios.
- Payloads up to 3.5 tons.

Benolol, S. and Zapirain, F. The fastwing project, parafoil development and manufacturing. *18th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar. AIAA paper 2005-1639,* 2005

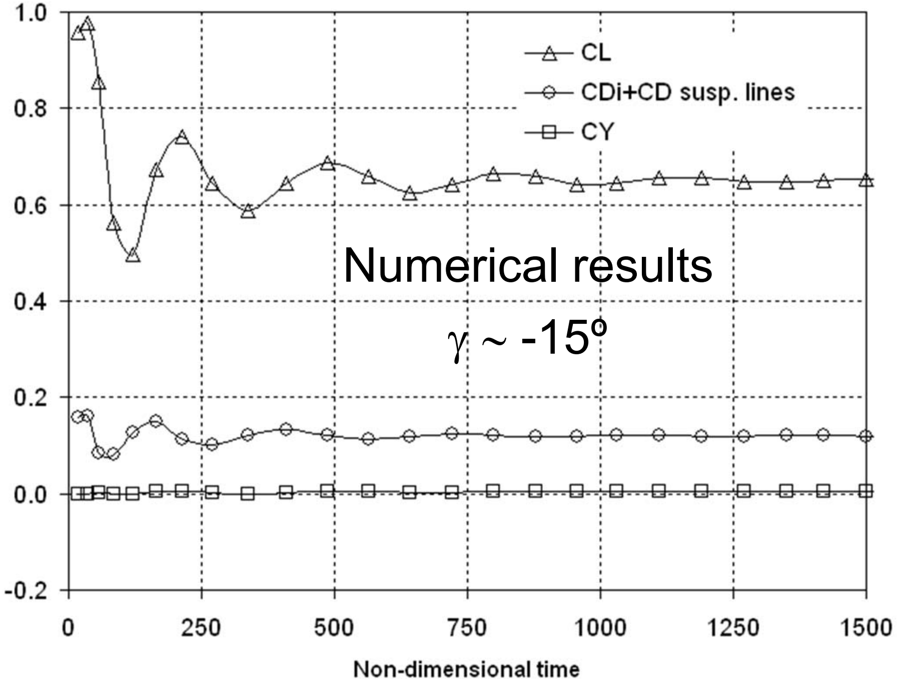


V_{∞} = 24 m/s

Equilibrium angle of descent ~ -15º

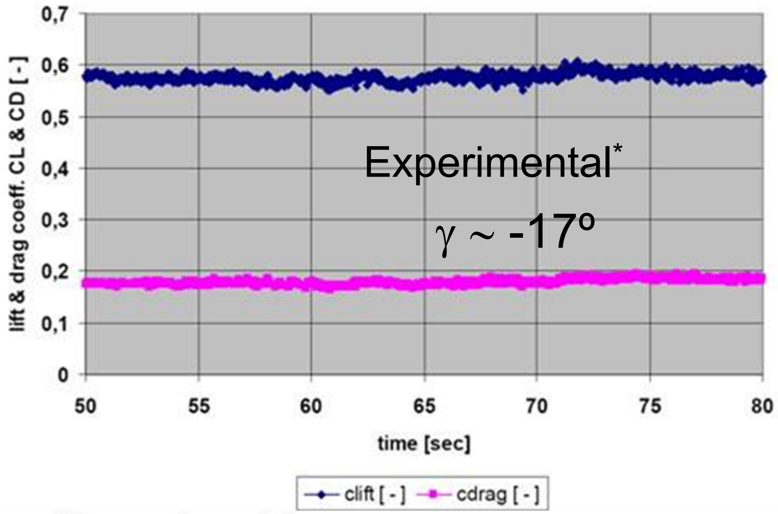


Fastwing stationary results (under-relaxation is applied)



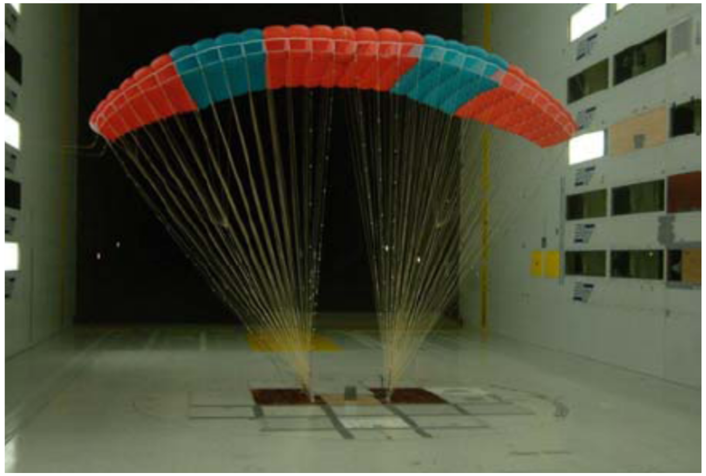
Numerical results

$\gamma \sim -15^{\circ}$



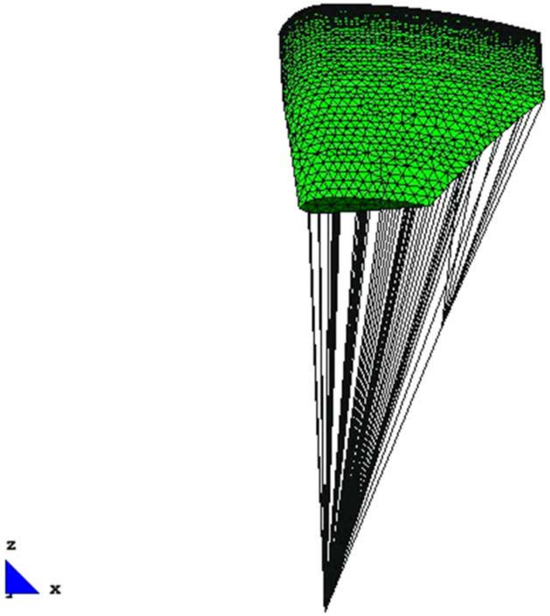
Experimental*

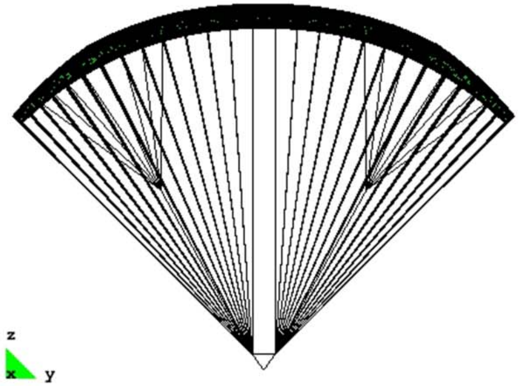
$\gamma \sim -17^{\circ}$



*The analysis model geometry and the experimental results were provided by CIMSA. Additional references: Hollestelle, P. The FASTWing Project: Wind tunnel test. Realisation and results. *18th AIAA Aerodynamic Decelerator Systems Technology Conference and Seminar. AIAA paper 2005-1641,* 2005

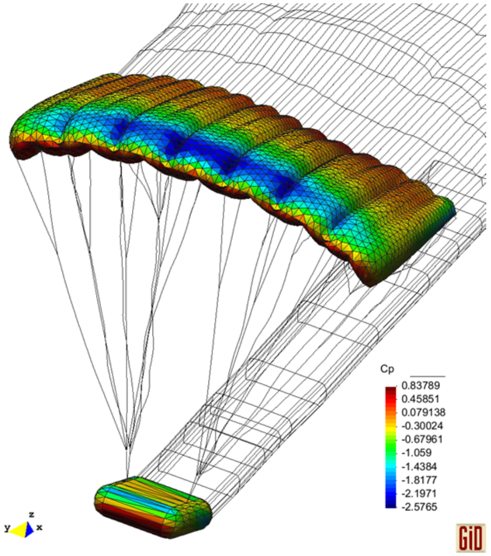
Turn-right maneuver

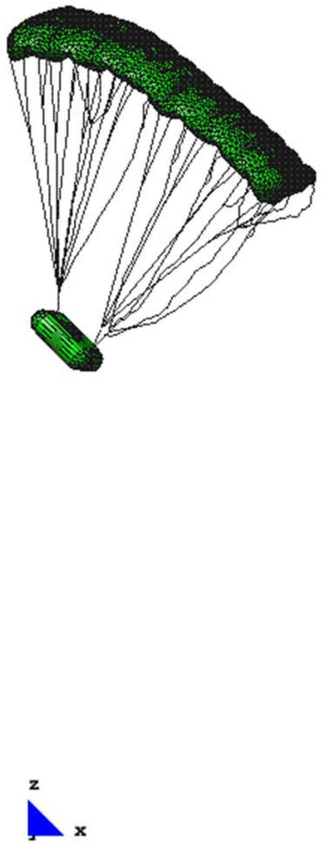




Application example 2 - Manoeuvring

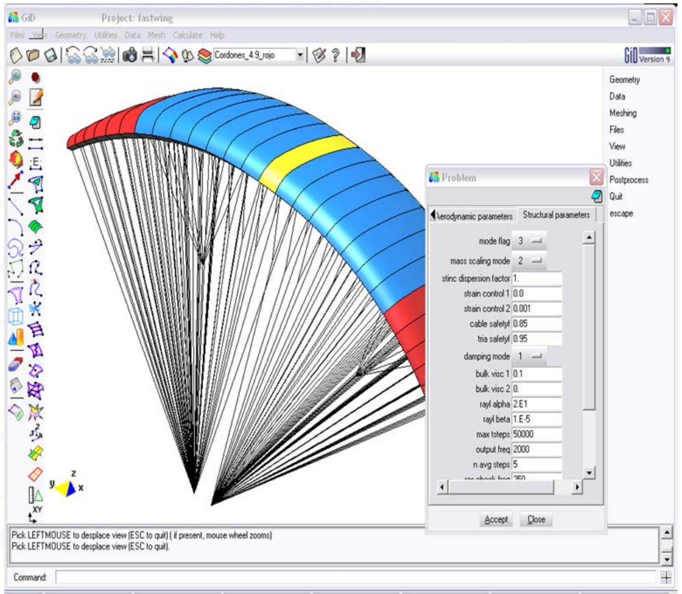
- CIMSA personal parachute.
- Payload 120 Kg.





PARACHUTES: Graphical User Interface (GUI)

- Graphical user interface developed on the basis of the in-house pre and postprocessor GiD (www.gidhome.com).
- Creation and manipulation of complex CAD geometries.
- Customized window menus for the application of boundary conditions and the definition of the simulation parameters.



mode flag 3
mass scaling mode 2
stinc dispersion factor 1.
strain control 1 0.0
strain control 2 0.001
cable safetyf 0.85
tria safetyf 0.95
damping mode 1
bulk visc 1 0.1
bulk visc 2 0.
rayl alpha 2.E1
rayl beta 1.E-5
max tsteps 50000
output freq 2000
n avg steps 5

```
Pick LEFTMOUSE to desplace view (ESC to quit) ( if present, mouse wheel zooms)
Pick LEFTMOUSE to desplace view (ESC to quit).
```

- All the necessary tools for generating structured and non-structured meshes in complex geometries are provided.
- Specific templates for the automatic generation of code input files.
- Wide range of possibilities for the analysis and visualization of the numerical results.

PARASIM6: An overview

- ParaSim6 is a tool set for designing and analyzing precision delivery systems.
- A parametric **6 DoF parafoil-payload (rigid) model** provides fast simulations for multiple configurations / scenarios. Independent left / right brake inputs for lateral control and variable incidence angle for longitudinal control.
- The trajectory calculation module accounts for:

Parafoil aerodynamics (derivatives based model), inertia, apparent mass, etc.

Wind conditions and atmosphere model.

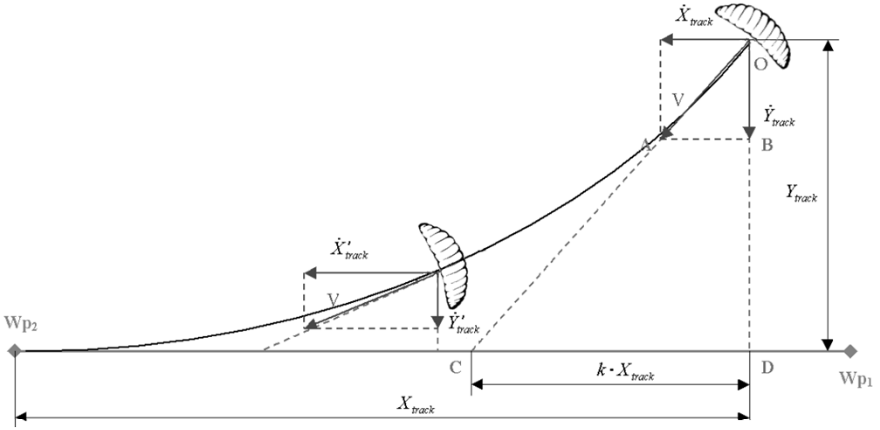
Payload weight, drop altitude, airspeed and heading.

- Aerodynamic parameters estimation through experimental data or numerical simulation (current approach ⇒ unsteady panel code + FEM model for the structure).
- Modular Guidance Navigation and Control (GNC) subroutine for user-defined algorithms.

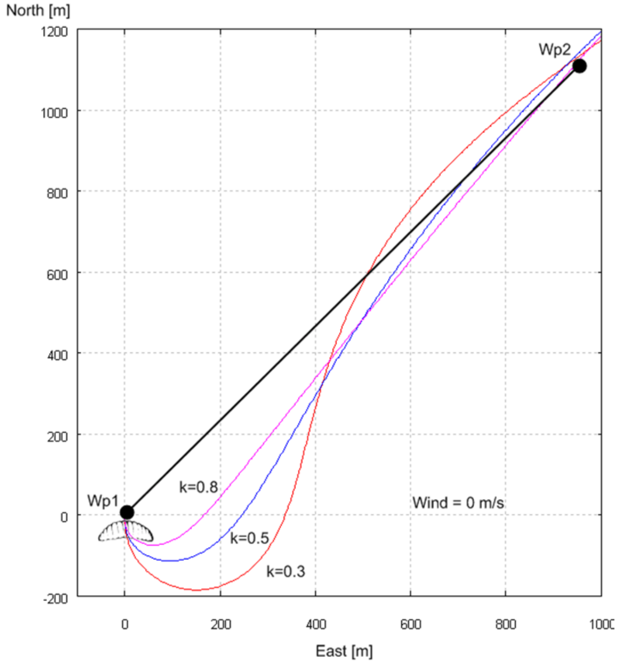
PARASIM6: The 6-DoF model

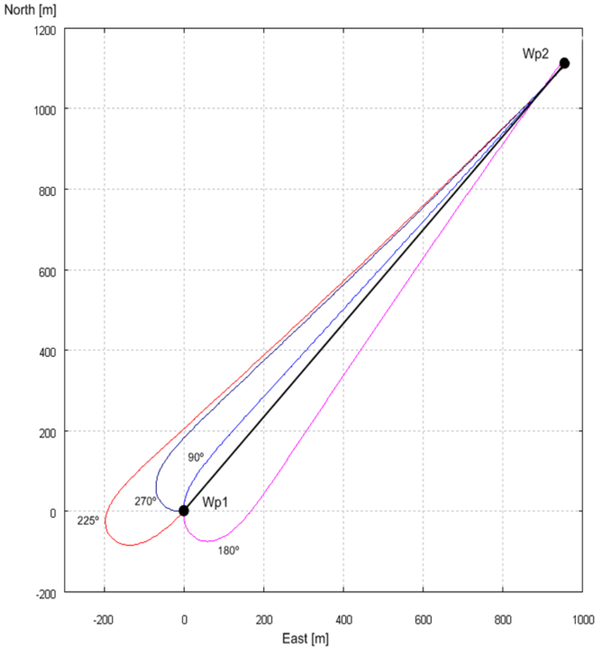
- Parafoil-payload load system considered a single rigid body with 6 degrees of freedom
- Aerodynamic model based on derivatives
- Apparent mass model based on Barrows
- Variable incidence angle for longitudinal (glide slope) control
- Standard atmosphere and wind input capability
- Guidance, Navigation and Control (GNC) algorithm
  - Lateral Control Strategy implemented similar to PID navigation of the Aerosonde UAV
  - Altitude Control Strategy deals with potential energy management

PARASIM6: Lateral control strategy

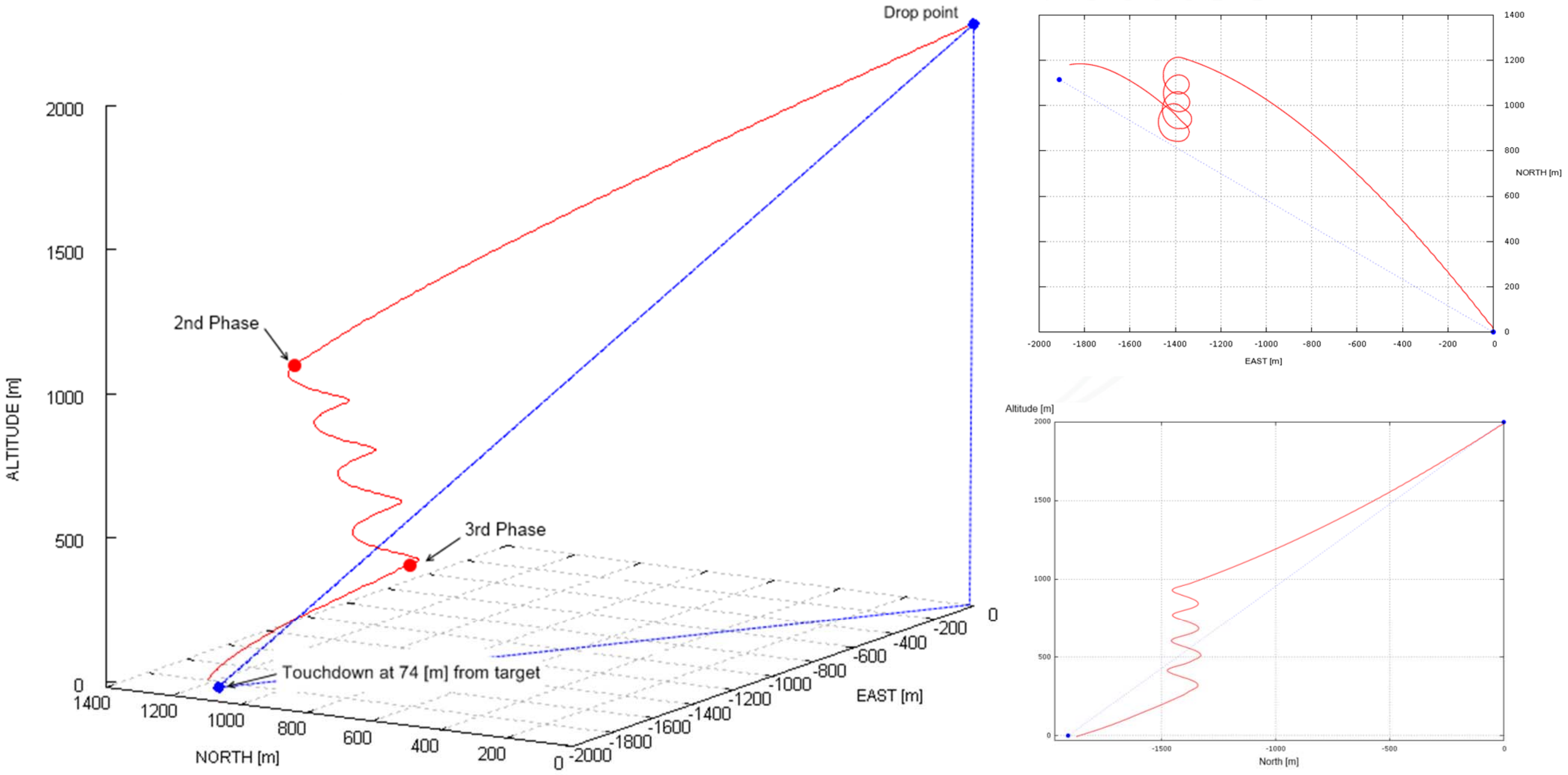


$$r_{CMD} = K_R E = K_R\left(k\cdot X_{track}\dot{Y}_{track} - Y_{track}\dot{X}_{track}\right)$$





PARASIM6: Trajectory example

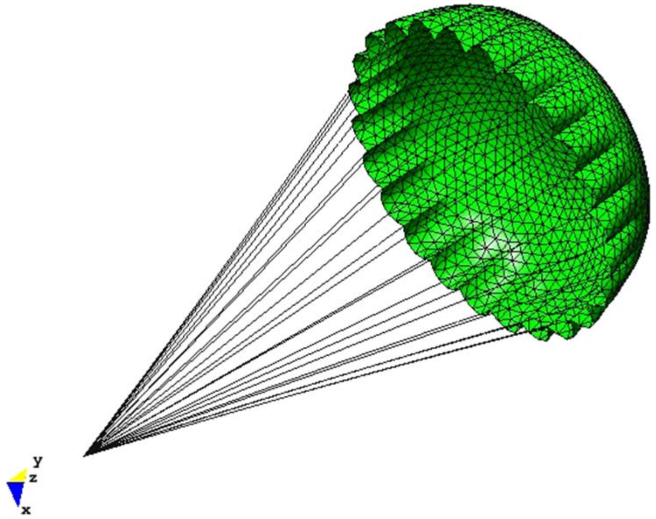


Conclusions

- A set of computational tools for aerodynamics, structures and flight mechanics of parachutes have been developed. These tools are useful from early design to operational stages of parachutes.
- Fast simulations for trajectory estimation or control algorithm development can be made through **ParaSim6** (6 DoF)
- Detailed aerodynamics, derivatives estimation and maneuver analysis can be made through the coupled solver **PARACHUTES**.

Ongoing and Future work

- Study of parachute deployment and inflation (semi-empirical models). Analysis of vortex methods for simulating flow separation (intended for circular canopies)
- Improved reefing strategies (sliding cables and contact algorithms).
- Improvements to the parachute flight simulator capabilities: Automatic aerodynamic parameters estimation subroutine (based on PARACHUTE code) and Monte-Carlo simulations for sensitivity analysis



Questions?
Thanks!

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