Dinamica e simulazione di volo

Laurea Magistrale, I anno, 6CFU

prof. Domenico Coiro

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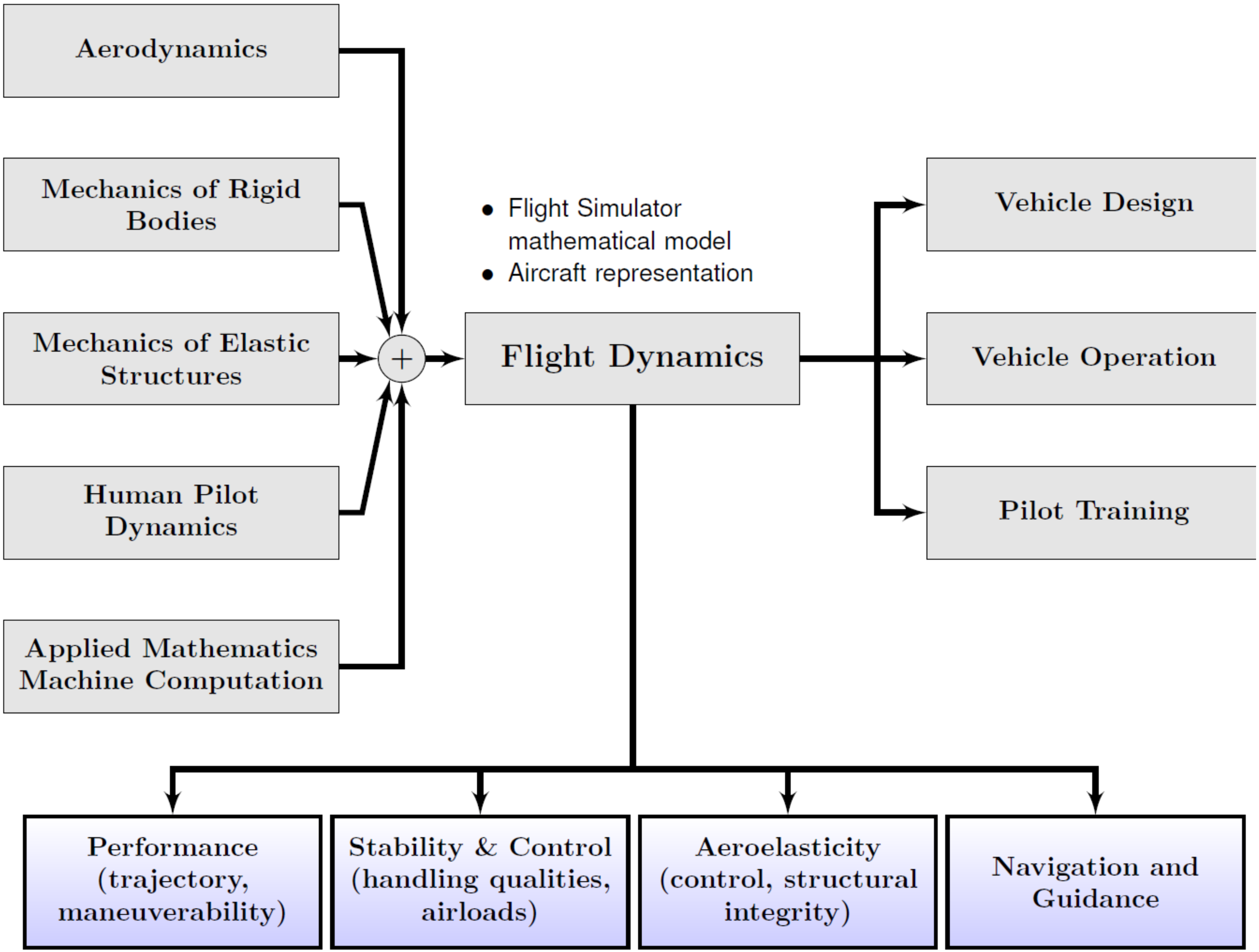
prof. Domenico Coiro: domenico.coiro@unina.it

Ricevimento: lunedì, 15:00 — 17:00; mercoledì, 11:00 — 13:00 (su appuntamento)


Aerodynamics
Mechanics of Rigid Bodies
Mechanics of Elastic Structures
Human Pilot Dynamics
Applied Mathematics Machine Computation
+
Flight Simulator mathematical model
Aircraft representation
Flight Dynamics
Vehicle Design
Vehicle Operation
Pilot Training
Performance (trajectory, maneuverability)
Stability & Control (handling qualities, airloads)
Aeroelasticity (control, structural integrity)
Navigation and Guidance

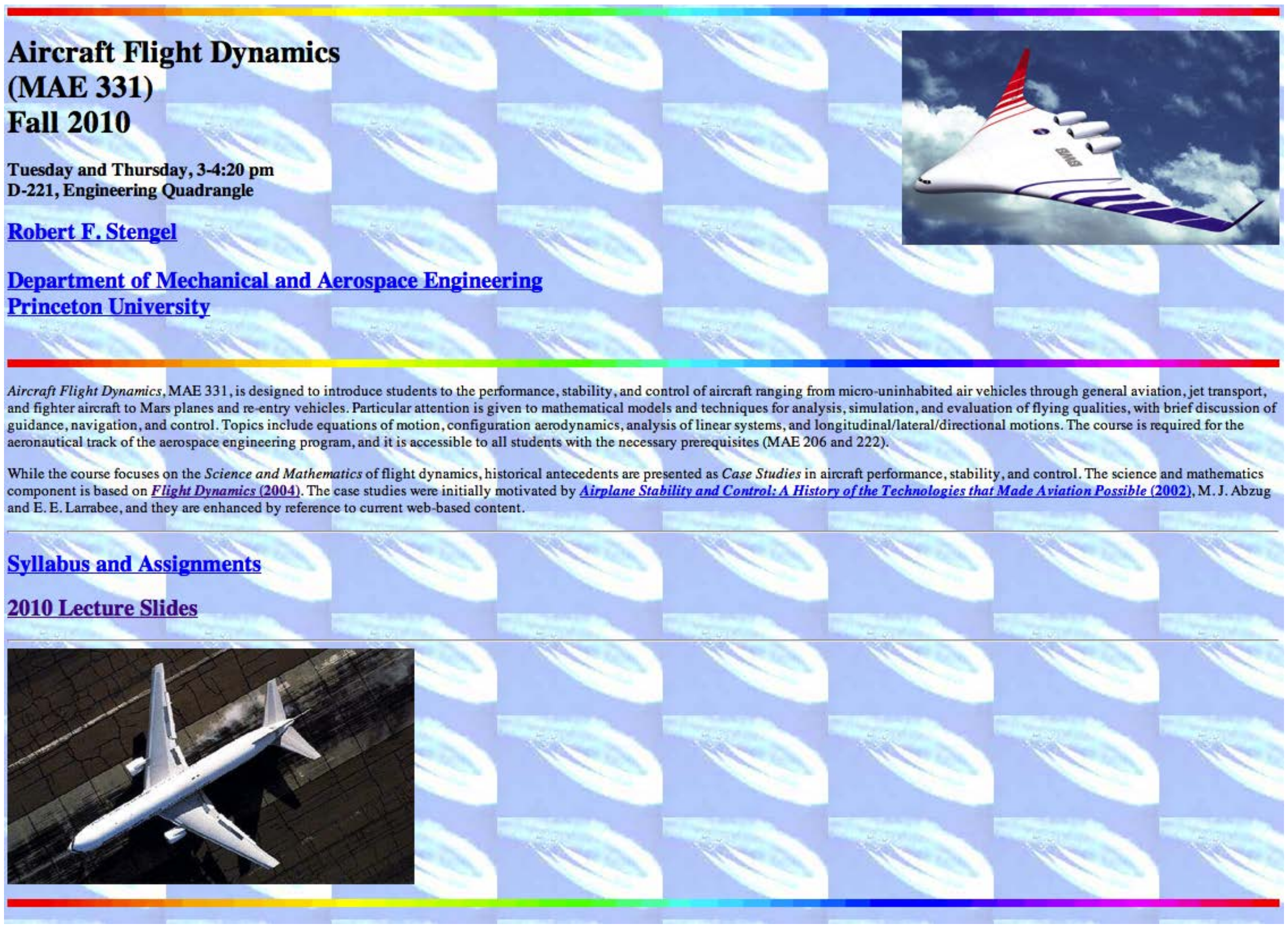
Riferimenti

- Abzug, M., and Larrabee, E., *Airplane Stability and Control: A History of the Technologies that Made Aviation Possible*, Cambridge University Press, 2002.
- Anderson, J., *Fundamentals of Aerodynamics*, McGraw-Hill, 2011.
- Cook, M., *Flight Dynamics Principles*, Elsevier, 2007.
- Etkin, B., and Reid, L., *Dynamics of Flight: Stability and Control*, J. Wiley & Sons, 1996.
- Gibson, J., *The Definition, Understanding and Design of Aircraft Handling Qualities*, Delft University Press, 1997.
- Hodgkinson, *Aircraft Handling Qualities*, AIAA Press, 1999.
- Lowry, J., *Performance of Light Aircraft*, AIAA Education Series, 1999.
- McClamroch, N. H., *Steady Aircraft Flight and Performance*, Princeton University Press, 2011.
- McCormick, B., *Aerodynamics, Aeronautics, and Flight Mechanics*, J. Wiley & Sons, 1994.
- McRuer, D., Ashkenas, I., and Graham, D, *Aircraft Dynamics and Automatic Control*, Princeton University Press, 1973.
- Miele, A., *Flight Mechanics: Theory of Flight Paths*, Addison-Wesley, 1962.
- Nelson, R., *Flight Stability and Automatic Control*, McGraw Hill, 1998.
- Pamadi, B., *Performance, Stability, Dynamics, and Control of Airplanes*, AIAA Press, 2004.
- Perkins, C., and Hage, R., *Airplane Performance Stability and Control*, J. Wiley & Sons, 1949.
- Phillips, W. F., *Mechanics of Flight*, J. Wiley & Sons, 2004.
- Raymer, D., *Aircraft Design: A Conceptual Approach*, AIAA Press, 1989.
- Schlichting, H., and Truckenbrodt, E., *Aerodynamics of the Airplane*, McGraw-Hill Book Co., 1979.
- Schmidt, L., *Introduction to Aircraft Flight Dynamics*, AIAA Press, 1998
- Stengel, R., *Flight Dynamics*, Princeton University Press, 2004.
- Stevens, B., and Lewis, F., *Aircraft Control and Simulation*, J. Wiley & Sons, 2004.
- Stinton, D.,*The Anatomy of the Airplane*, AIAA Press, 1998.

Riferimenti

M. Calcara, *Elementi di dinamica del velivolo*. Edizioni CUEN, Napoli, 1988.

J. Roskam, *Airplane Flight Dynamics and Automatic Flight Controls*. DARcorporation, 2001.



Aircraft Flight Dynamics
(MAE 331)
Fall 2010

Tuesday and Thursday, 3-4:20 pm
D-221, Engineering Quadrangle

Robert F. Stengel

Department of Mechanical and Aerospace Engineering
Princeton University

Aircraft Flight Dynamics, MAE 331, is designed to introduce students to the performance, stability, and control of aircraft ranging from micro-uninhabited air vehicles through general aviation, jet transport, and fighter aircraft to Mars planes and re-entry vehicles. Particular attention is given to mathematical models and techniques for analysis, simulation, and evaluation of flying qualities, with brief discussion of guidance, navigation, and control. Topics include equations of motion, configuration aerodynamics, analysis of linear systems, and longitudinal/lateral/directional motions. The course is required for the aeronautical track of the aerospace engineering program, and it is accessible to all students with the necessary prerequisites (MAE 206 and 222).

While the course focuses on the *Science and Mathematics* of flight dynamics, historical antecedents are presented as *Case Studies* in aircraft performance, stability, and control. The science and mathematics component is based on ***Flight Dynamics* (2004)**. The case studies were initially motivated by ***Airplane Stability and Control: A History of the Technologies that Made Aviation Possible* (2002)**, M. J. Abzug and E. E. Larrabee, and they are enhanced by reference to current web-based content.

Syllabus and Assignments

2010 Lecture Slides

http://www.princeton.edu/~stengel/MAE331.html

Riferimenti

Marcello R. Napolitano,
***Aircraft Dynamics. From Modelling to Simulation*.**
John Wiley & Sons, November 2011.
ISBN: 0470626674
ISBN-13: 9780470626672

www.amazon.com/Aircraft-Dynamics-Simulation-Marcello-Napolitano/dp/0470626674

Riferimenti

http://ocw.mit.edu/courses/aeronautics-and-astronautics/16-333-aircraft-stability-and-control-fall-2004

Riferimenti

http://ocw.mit.edu/courses/aeronautics-and-astronautics/16-31-feedback-control-systems-fall-2007

Riferimenti, software

USAF Digital DATCOM, en.wikipedia.org/wiki/USAF_Digital_DATCOM

FlightGear, www.flightgear.org

JSBSim, www.jsbsim.org

Scicoslab, www.scicoslab.org

Matlab/Simulink, http://www.mathworks.com

Cygwin, www.cygwin.com

Code::Blocks, www.codeblocks.org

Microsoft Visual Studio 2010 Express, Visual C++
www.microsoft.com/express/Downloads/#2010-Visual-CPP

DATCOM+

Holy Cows, Inc.

3757 Lake Drawdy Drive

Orlando, FL 32820

billg *at* holycows.net

Datcom+

Downloads

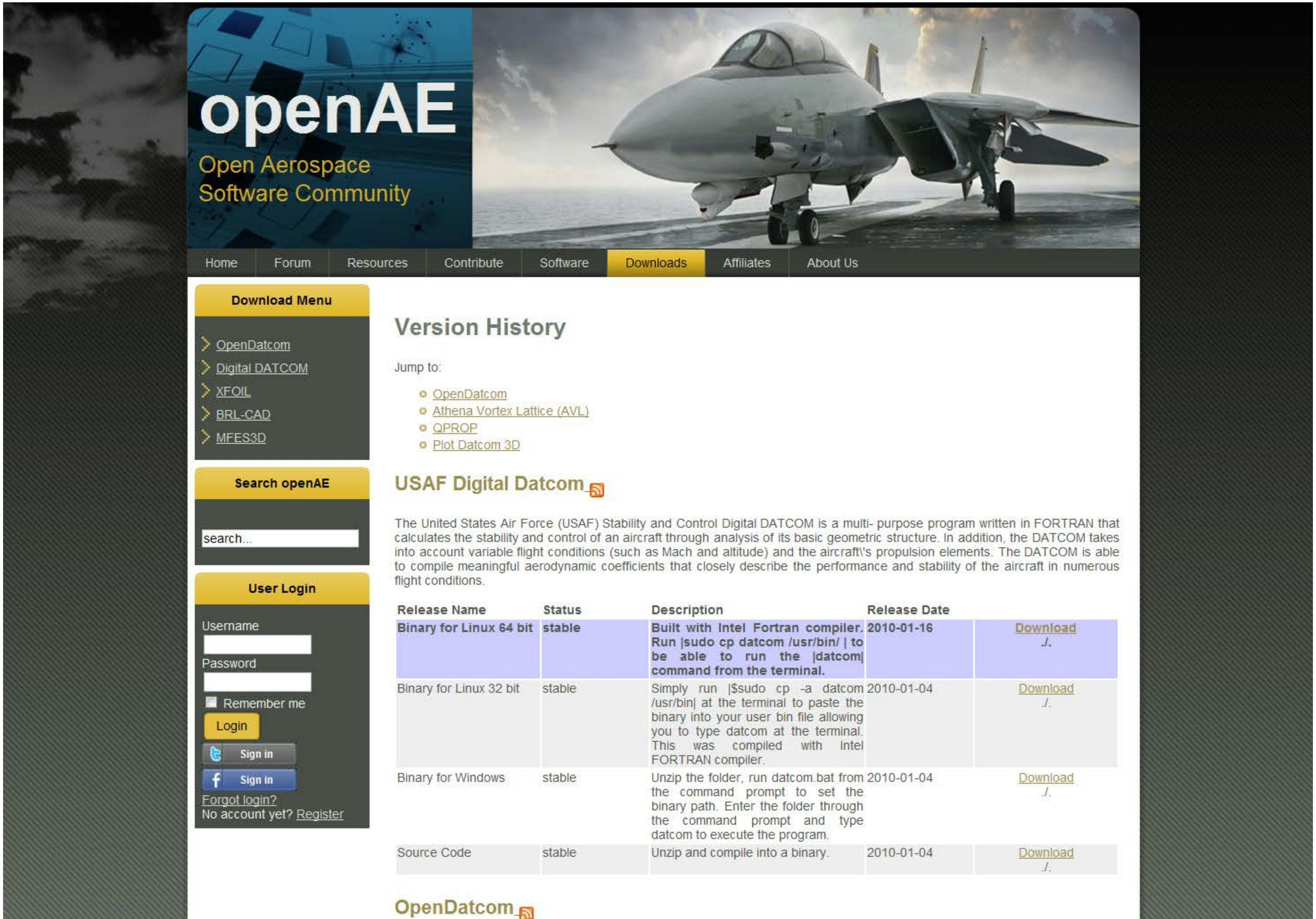
January 26, 2011

I fixed the AC3D output for the fuselage. For example, the B-737 aft fuselage didn't slope up to meet the horizontal tail.

- **Datcom_Windows_2.8.1.exe**
- **Datcom_Linux_2.8.1.tar**

http://www.holycows.net/datcom/

OpenDatcom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- Digital DATCOM
- XFOIL
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- MFES3D

Search openAE

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User Login

Username

Password

Remember me

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Sign in

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Forgot login?
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Version History

Jump to:

- OpenDatcom
- Athena Vortex Lattice (AVL)
- QPROP
- Plot Datcom 3D

USAF Digital Datcom

The United States Air Force (USAF) Stability and Control Digital DATCOM is a multi- purpose program written in FORTRAN that calculates the stability and control of an aircraft through analysis of its basic geometric structure. In addition, the DATCOM takes into account variable flight conditions (such as Mach and altitude) and the aircraft\'s propulsion elements. The DATCOM is able to compile meaningful aerodynamic coefficients that closely describe the performance and stability of the aircraft in numerous flight conditions.

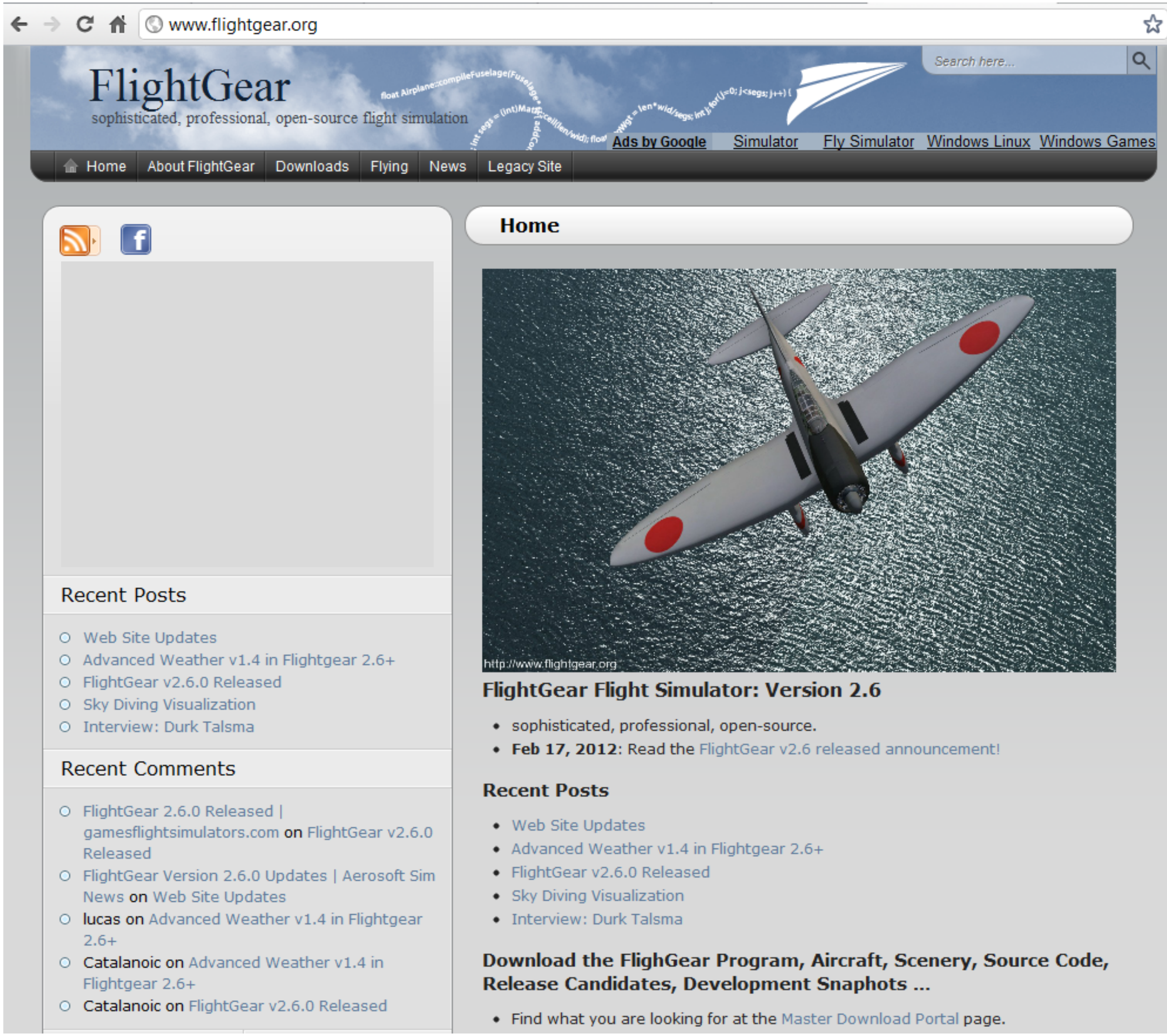
Release Name	Status	Description	Release Date	
Binary for Linux 64 bit	**stable**	**Built with Intel Fortran compiler. Run |sudo cp datcom /usr/bin/ | to be able to run the |datcom| command from the terminal.**	**2010-01-16**	**Download** ./.
Binary for Linux 32 bit	stable	Simply run |$sudo cp -a datcom /usr/bin| at the terminal to paste the binary into your user bin file allowing you to type datcom at the terminal. This was compiled with Intel FORTRAN compiler.	2010-01-04	Download ./.
Binary for Windows	stable	Unzip the folder, run datcom.bat from the command prompt to set the binary path. Enter the folder through the command prompt and type datcom to execute the program.	2010-01-04	Download ./.
Source Code	stable	Unzip and compile into a binary.	2010-01-04	Download ./.

OpenDatcom

http://openae.org/downloads

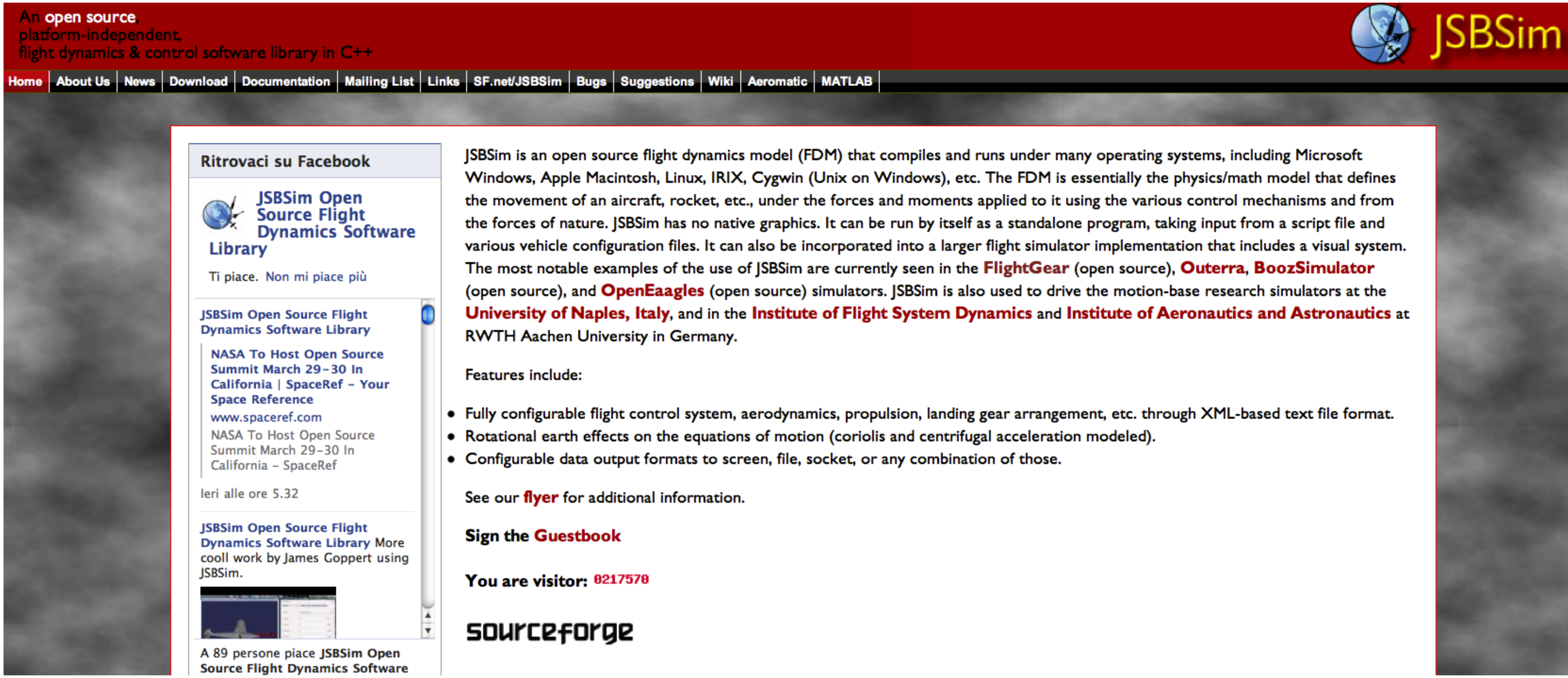
FlightGear

v.2.6 (2012)



http://www.flightgear.org

JSBSim



http://www.jsbsim.org

Scicoslab

ScicosLab

Introduction
Cvs access
Git access
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Documents
YouTube

Tiddlywiki 2.5.0

close close others **view** more

Introduction

Jpc, 6 January 2011 (created 2 December 2007)

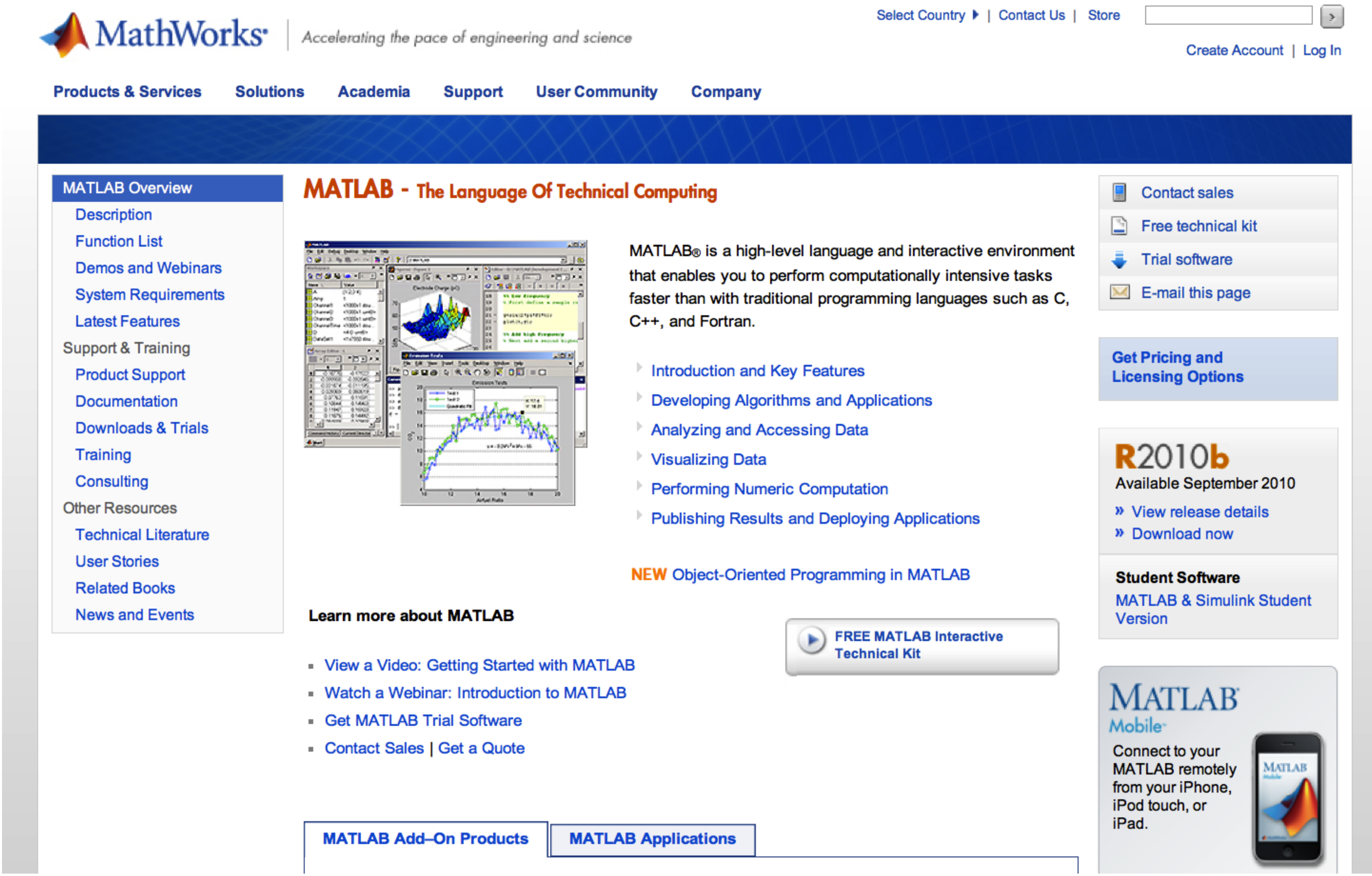
no tags

The latest version of ScicosLab available on this site is ScicosLab 4.4.
January 06,2011: some packaged binaries for ScicosLab 4.4 are now available, more packages will come soon.

ScicosLab is the new name of ScilabGtk. This change of name has been decided in order to avoid all confusion with Scilab, which is no longer developed at INRIA. ScicosLab is developed by some of the researchers who originally developed Scilab at INRIA and ENPC. ScicosLab is used in particular for disributing new software developments stemming from research activities of the Metalau team at INRIA and ENPC, such as Scicos (Scicos 4.3 in ScicosLab 4.3) and the Maxplus algebra toolbox.

ScicosLab is a Gtk+ version of Scilab, based on the official Scilab BUILD4 distribution. It aims at maintaining the Gtk+ port of Scilab instead of the default X11 graphical user interface. It can be compiled on Linux, or MacOSX-X11-Fink, or MacOSX-X11-MacPorts, or Windows-Cygwin. A set of binary packages are available for popular platforms (such as Linux Fedora, Debian, MacOSX, Windows). Note that the Win32 Windows binary have been obtained by cross-compilation on a Linux

Matlab/Simulink



Cygwin, compilatori gcc, g++, bash shell …

- Cygwin
  - Install Cygwin
  - Update Cygwin
  - Search Packages
  - Licensing Terms
- Cygwin/X
- Community
  - Reporting Problems
  - Mailing Lists
  - Newsgroups
  - Gold Stars
  - Mirror Sites
  - Donations
- Documentation
  - FAQ
  - User's Guide
  - API Reference
  - Acronyms
- Contributing
  - Snapshots
  - Source in CVS
  - Cygwin Packages
- Related Sites
- Red Hat Cygwin Product

Cygwin

Get that Linux feeling - on Windows!

This is the home of the Cygwin project

What...

...is it?

Cygwin is:

- a collection of tools which provide a Linux look and feel environment for Windows.
- a DLL (cygwin1.dll) which acts as a Linux API layer providing substantial Linux API functionality.

...isn't it?

Cygwin is not:

- a way to run native Linux apps on Windows. You must rebuild your application *from source* if you want it to run on Windows.
- a way to magically make native Windows apps aware of UNIX® functionality like signals, ptys, etc. Again, you need to build your apps *from source* if you want to take advantage of Cygwin functionality.

The Cygwin DLL currently works with all recent, commercially released x86 32 bit and 64 bit versions of Windows, with the exception of Windows CE.

For more information see the FAQ.

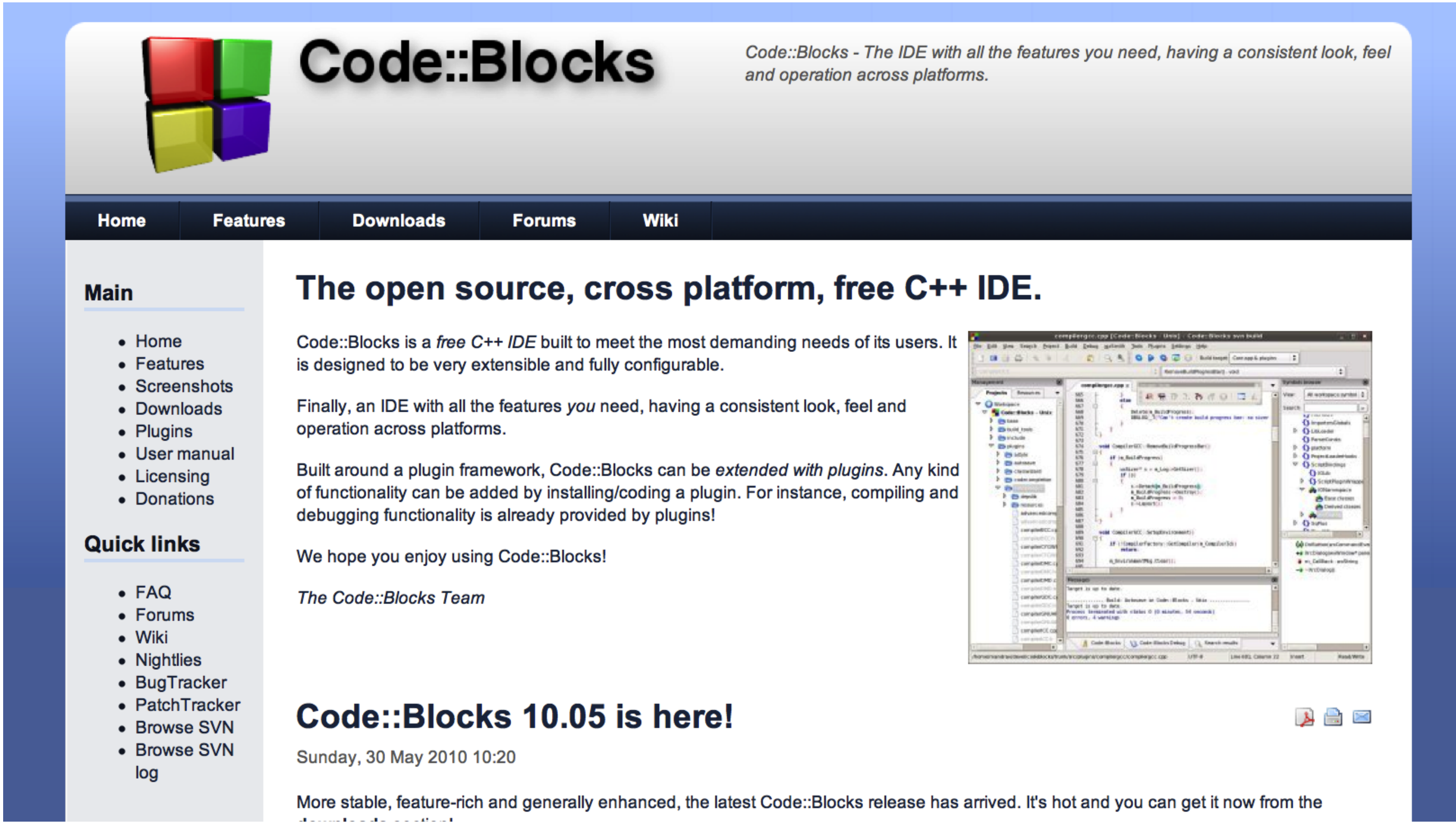
Current Cygwin DLL version

The most recent version of the Cygwin DLL is 1.7.8-1. Install it by running setup.exe.

Use setup.exe to perform a fresh install or to update an existing installation.

Note that individual packages in the distribution are updated separately from the DLL so the Cygwin DLL version is not useful as a general Cygwin release number.

Code::Blocks



Code::Blocks
Code::Blocks - The IDE with all the features you need, having a consistent look, feel and operation across platforms.
Home
Features
Downloads
Forums
Wiki
Main
Home
Features
Screenshots
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Plugins
User manual
Licensing
Donations
Quick links
FAQ
Forums
Wiki
Nightlies
BugTracker
PatchTracker
Browse SVN
Browse SVN log
The open source, cross platform, free C++ IDE.
Code::Blocks is a free C++ IDE built to meet the most demanding needs of its users. It is designed to be very extensible and fully configurable.
Finally, an IDE with all the features you need, having a consistent look, feel and operation across platforms.
Built around a plugin framework, Code::Blocks can be extended with plugins. Any kind of functionality can be added by installing/coding a plugin. For instance, compiling and debugging functionality is already provided by plugins!
We hope you enjoy using Code::Blocks!
The Code::Blocks Team
Code::Blocks 10.05 is here!
Sunday, 30 May 2010 10:20
More stable, feature-rich and generally enhanced, the latest Code::Blocks release has arrived. It's hot and you can get it now from the

Visual C++ 2010 Express

http://youtu.be/Mj9CZfYa3cI

Concetti introduttivi

Anatomia del velivolo

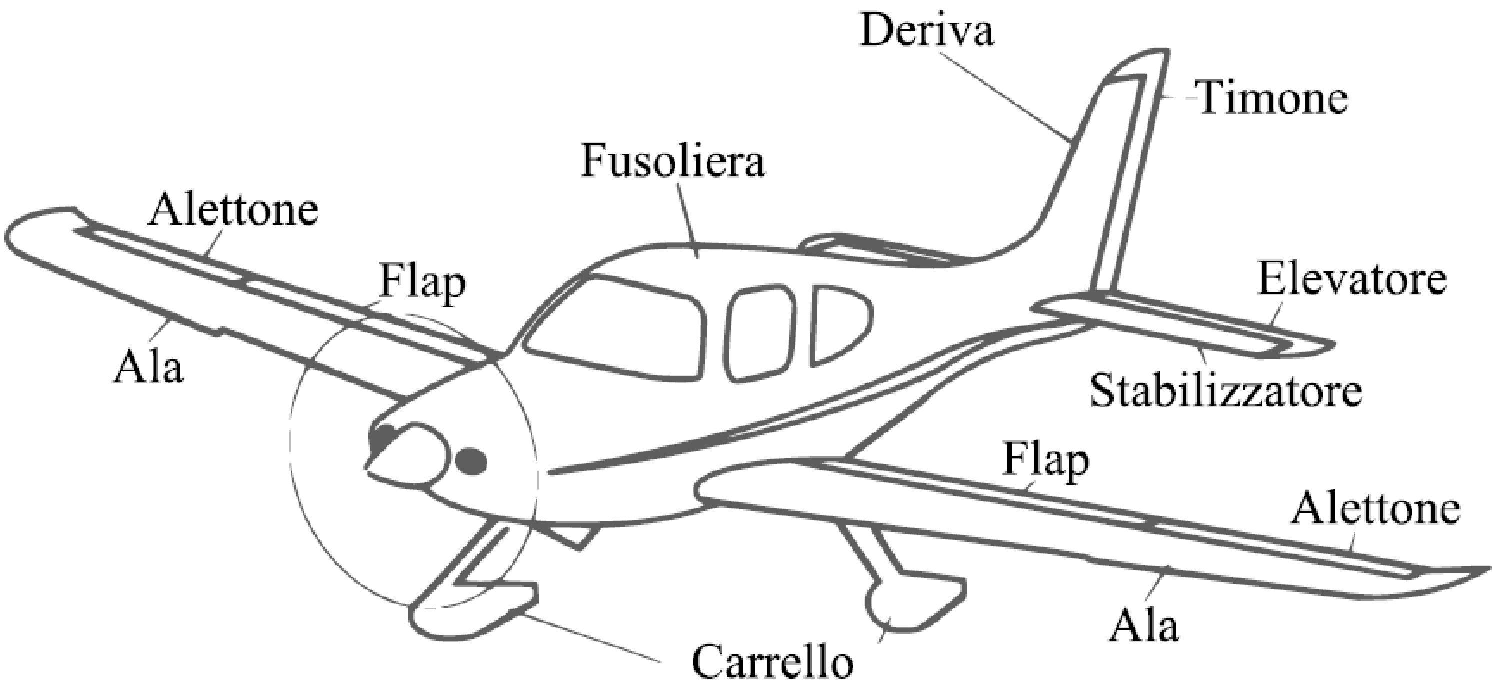


Figura 1.1 Anatomia di un velivolo di architettura tradizionale.

Anatomia del velivolo

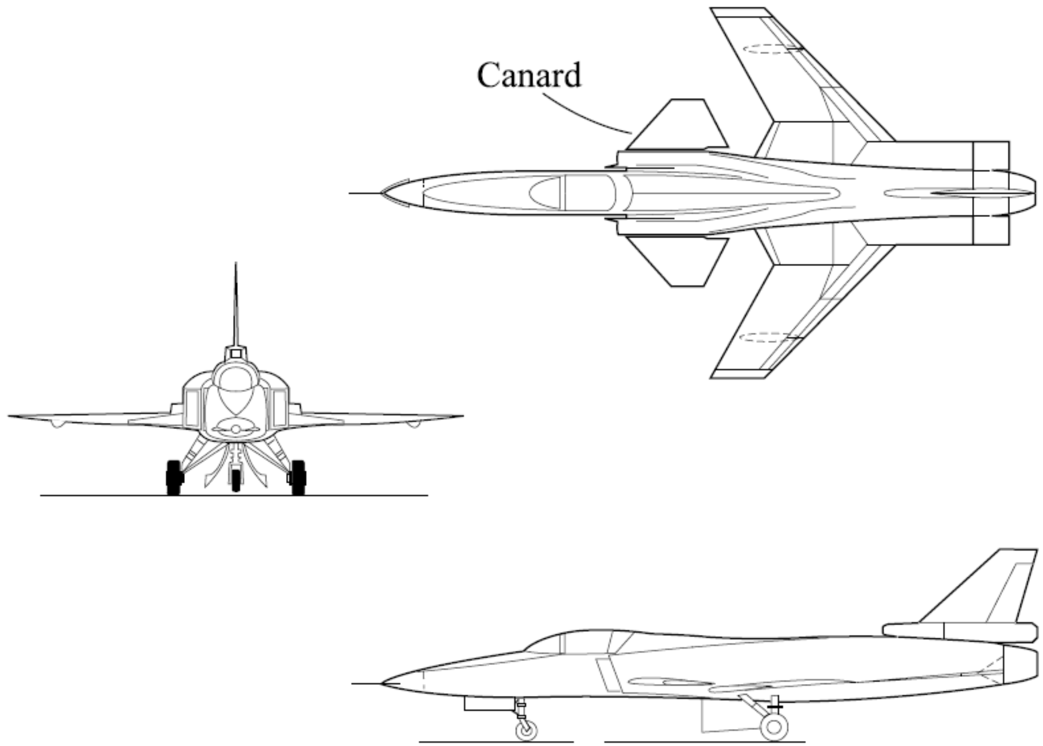
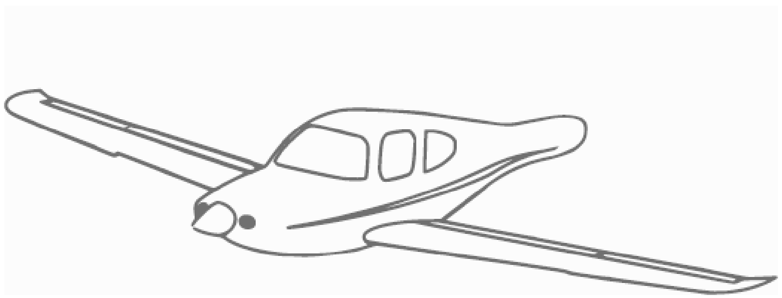


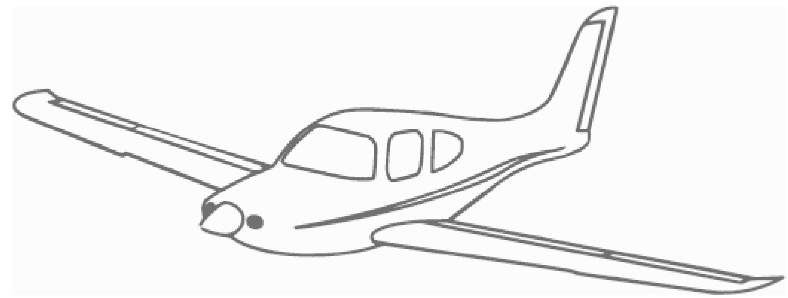
Figura 1.2 Un esempio di velivolo ad architettura non tradizionale, dotato di alette *canard* e di ali a freccia negativa, l'americano Grumman *X29*.

Anatomia del velivolo

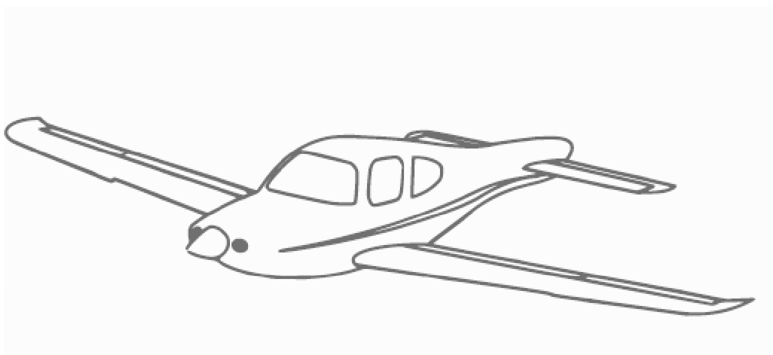
Scomposizione della configurazione aerodinamica



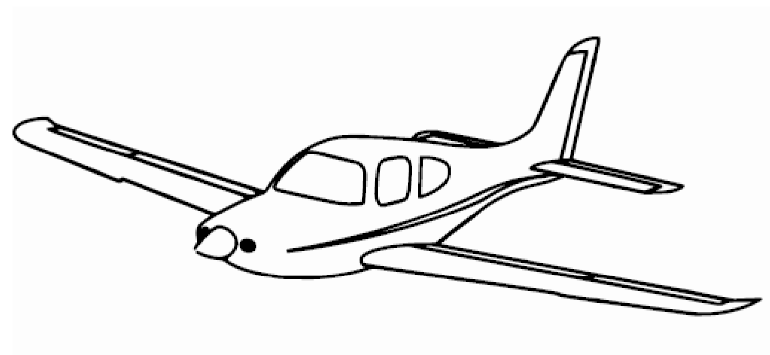
(a) *wing-body* (WB)



(b) *wing-body-vertical tail* (WBV)



(c) *wing-body-horizontal tail* (WBH)



(d) Velivolo completo

Figura 1.3 Possibili sottoinsiemi di una configurazione aerodinamica

$$F_{\mathrm{A}} = (F_{\mathrm{A}})_{\mathrm{WBV}} + (F_{\mathrm{A}})_{\mathrm{H}} + (F_{\mathrm{A}})_{\mathrm{I}}$$

Concetti introduttivi

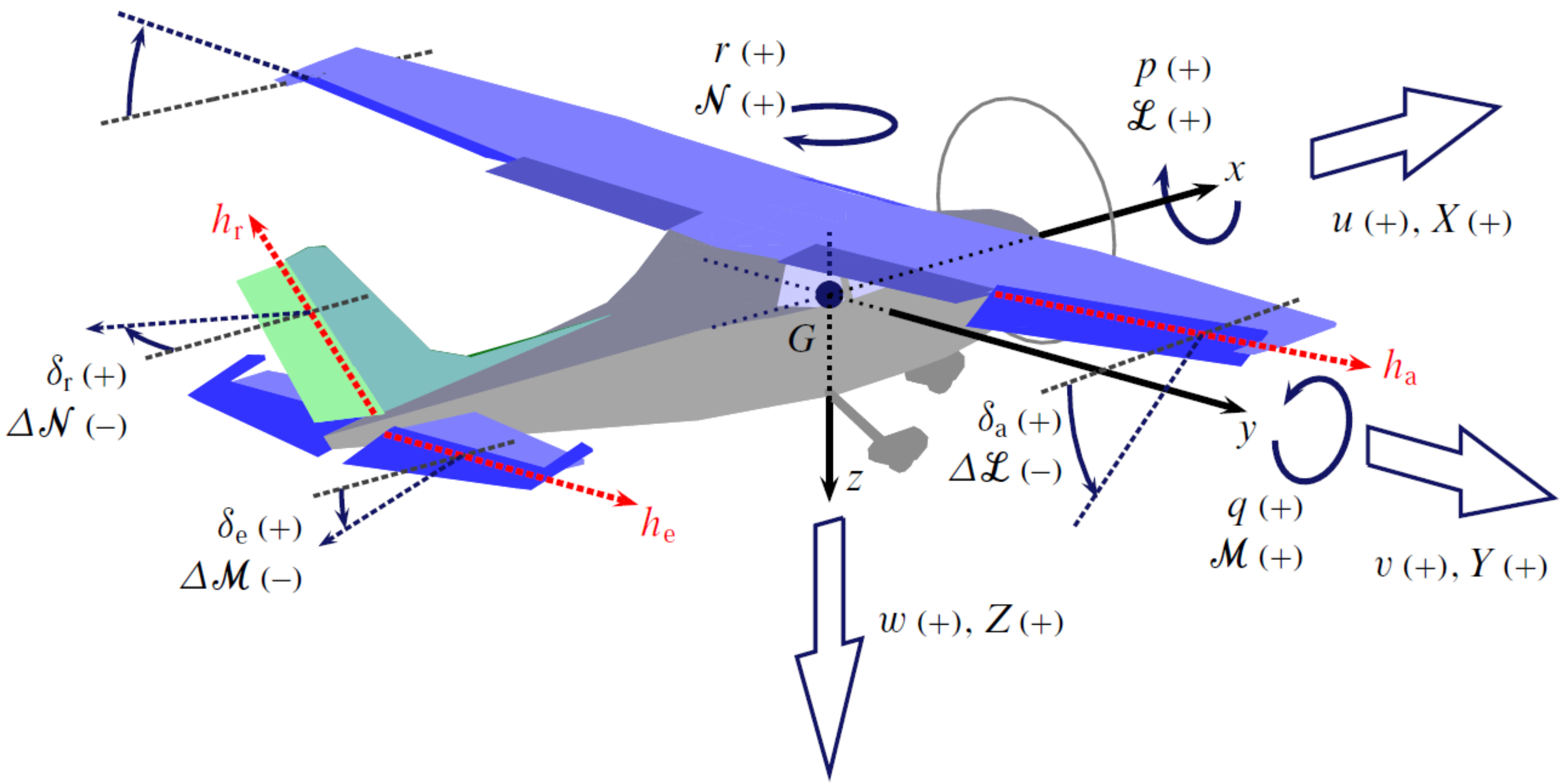
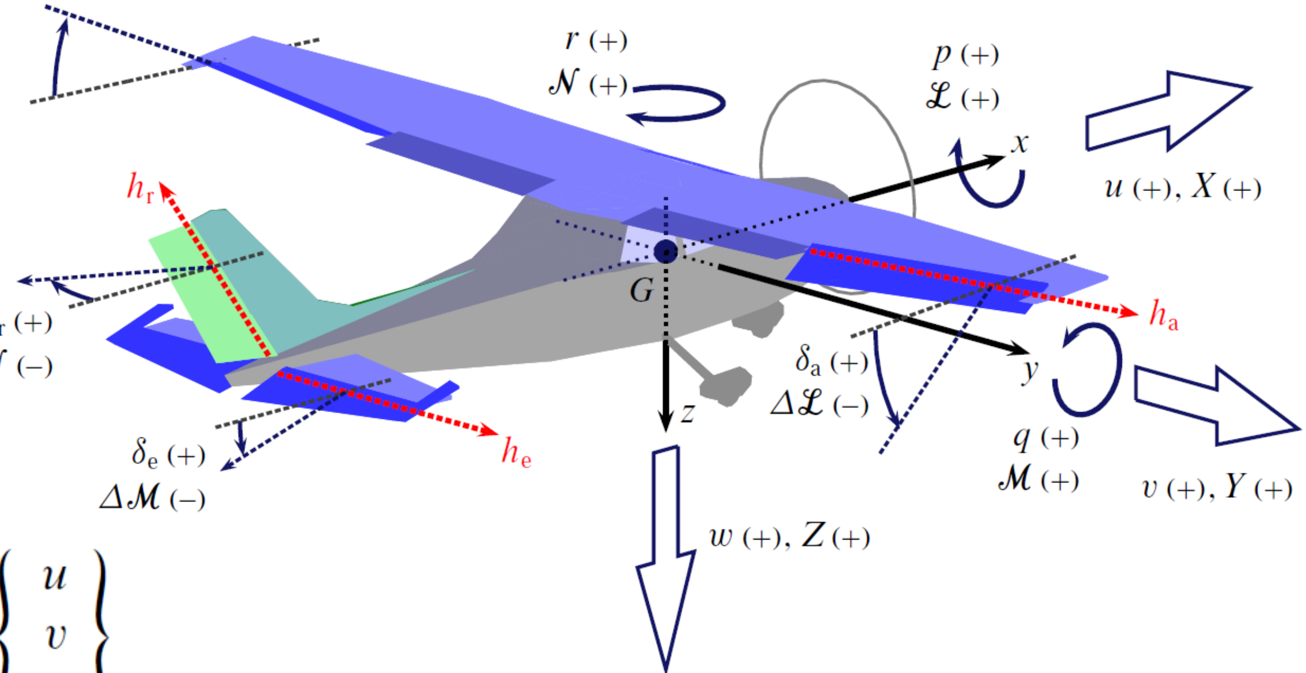


Figura 1.4 Sistema di assi velivolo e convenzioni sui segni.

$$X = X_A + X_T + X_G\,, \quad Y = Y_A + Y_T + Y_G\,, \quad Z = Z_A + Z_T + Z_G$$

Convenzioni



$$\boldsymbol{V} = u\,\boldsymbol{i} + v\,\boldsymbol{j} + w\,\boldsymbol{k} = \begin{Bmatrix} u \\ v \\ w \end{Bmatrix}$$

$$\boldsymbol{\Omega} = p\,\boldsymbol{i} + q\,\boldsymbol{j} + r\,\boldsymbol{k} = \begin{Bmatrix} p \\ q \\ r \end{Bmatrix}$$

$$\boldsymbol{F}_{\mathrm{A}} + \boldsymbol{F}_{\mathrm{T}} + \boldsymbol{F}_{\mathrm{G}} \qquad \boldsymbol{\mathcal{M}}_{\mathrm{A}} + \boldsymbol{\mathcal{M}}_{\mathrm{T}}$$

$$X = X_{\mathrm{A}} + X_{\mathrm{T}} + X_{\mathrm{G}}\,, \quad Y = Y_{\mathrm{A}} + Y_{\mathrm{T}} + Y_{\mathrm{G}}\,, \quad Z = Z_{\mathrm{A}} + Z_{\mathrm{T}} + Z_{\mathrm{G}}$$

Convenzioni sulle azioni di comando

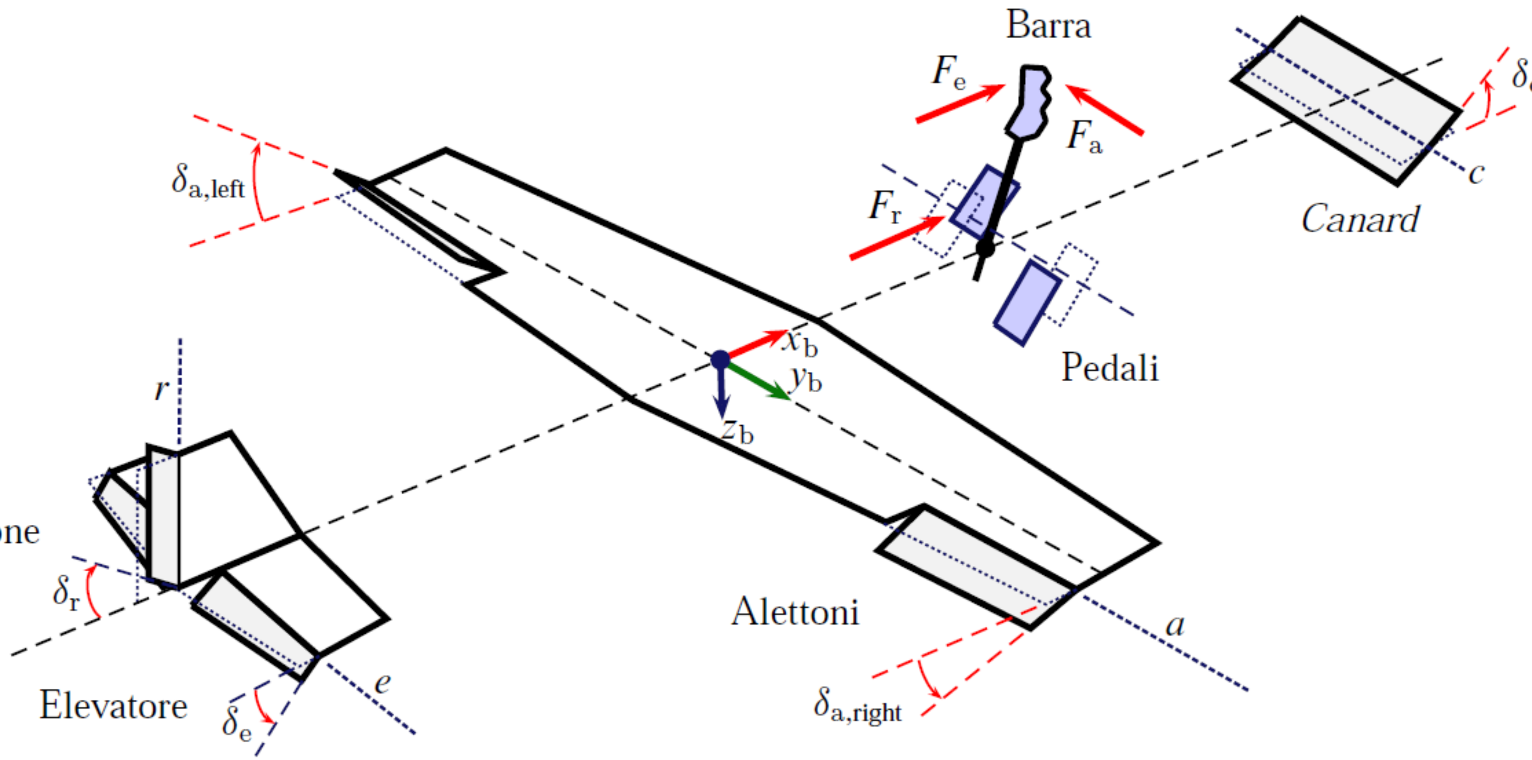


Figura 1.7 Forze positive applicate dal pilota secondo la convenzione europea e relazione con le convenzioni sui segni delle deflessioni delle superfici di governo.

Organi di governo

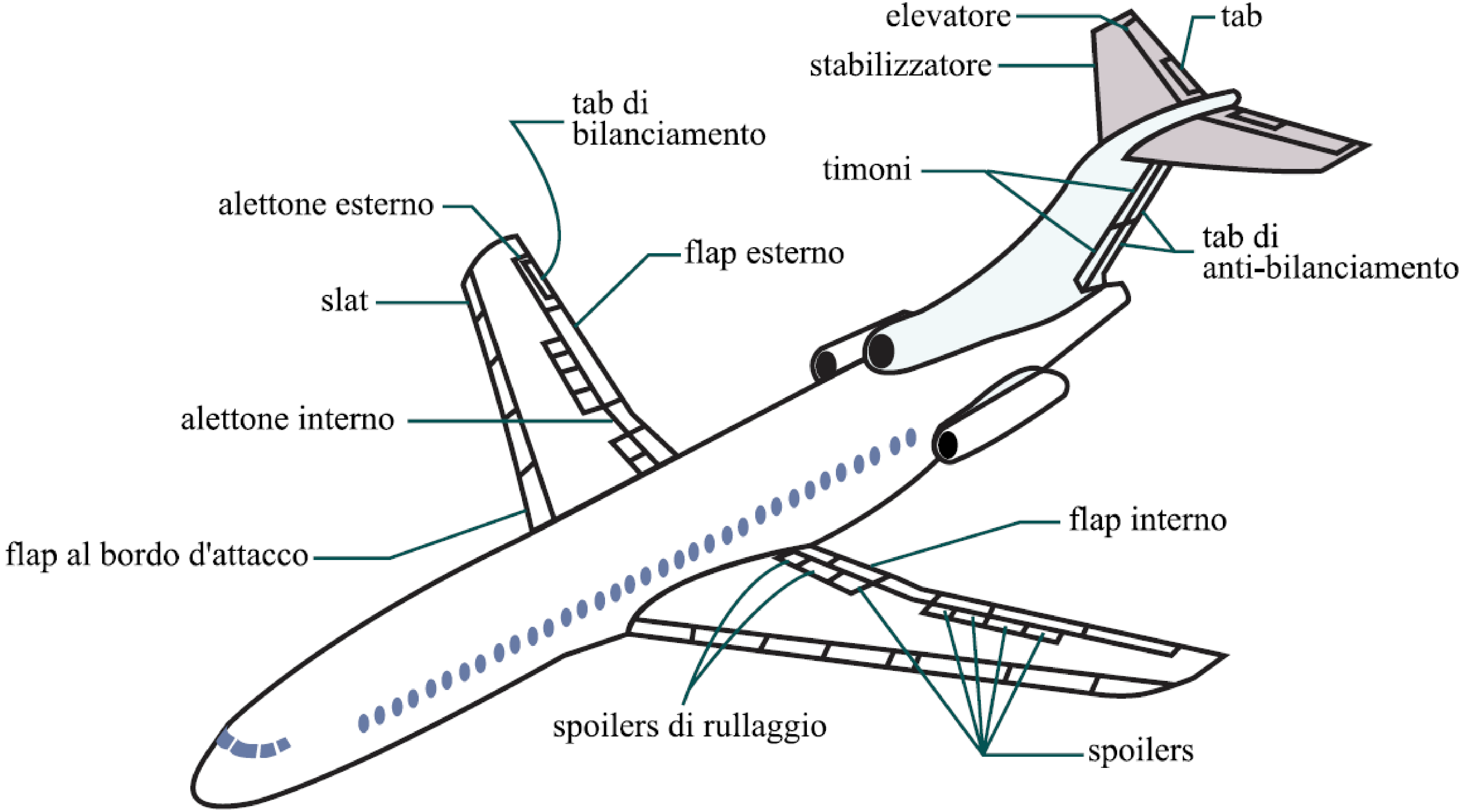
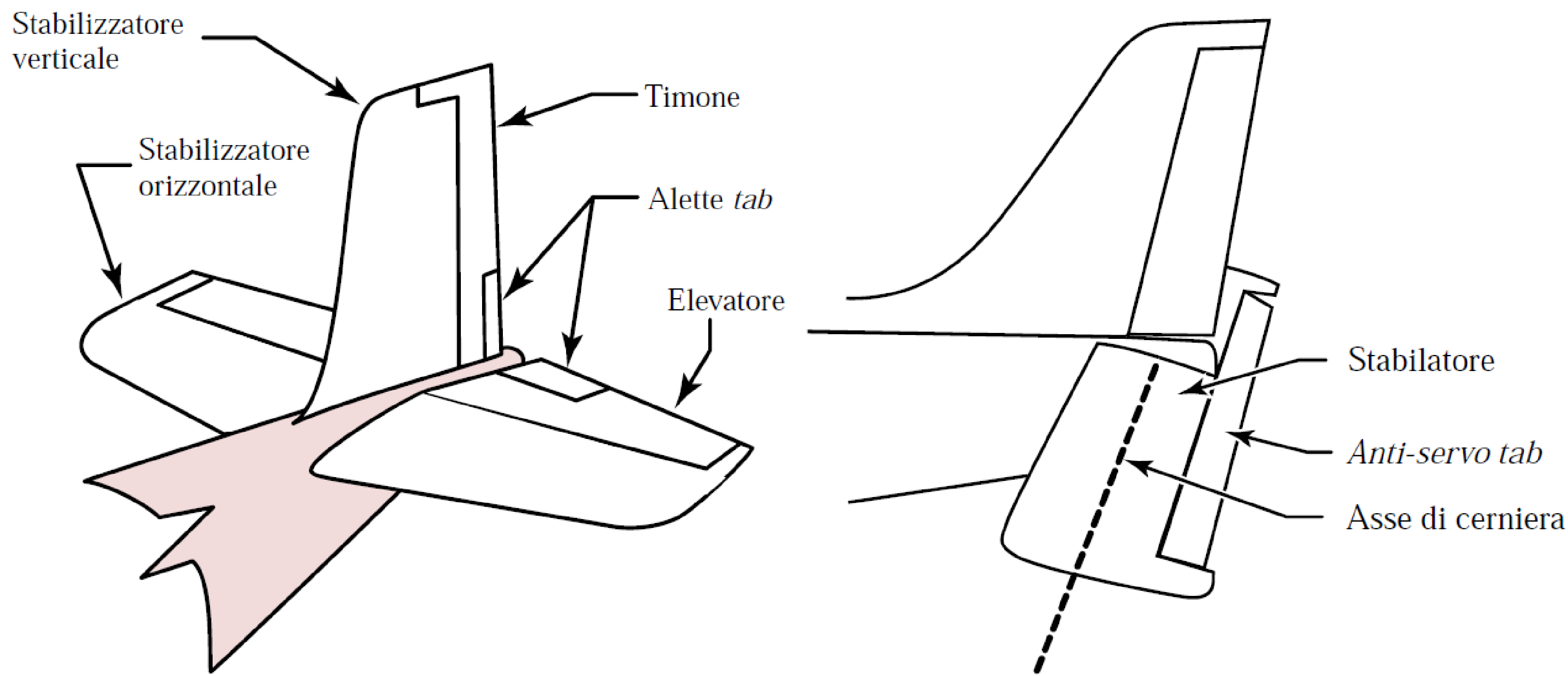


Figura 1.10 Superfici di governo di un velivolo da trasporto commerciale.

Impennaggi tradizionali



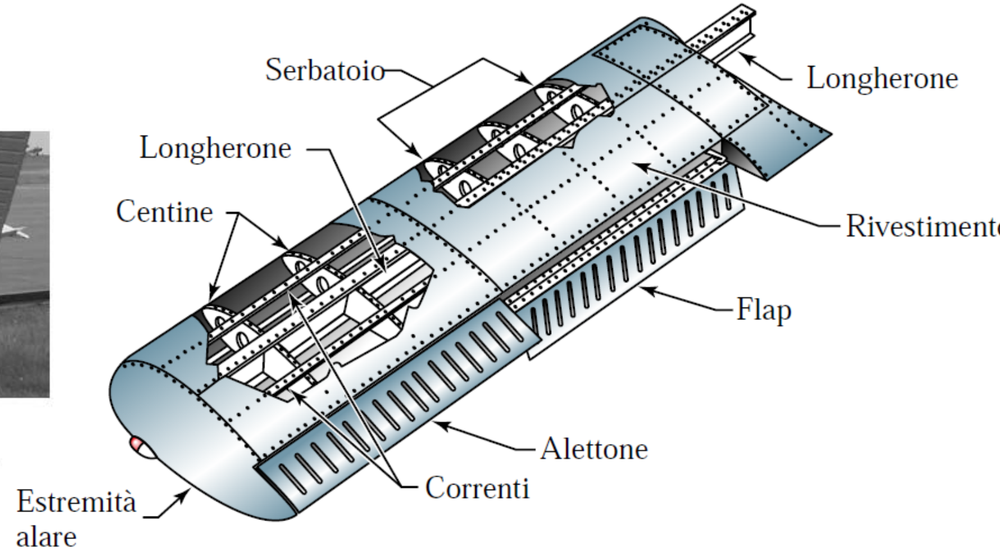
(a) Elevatore e timone di direzione.

(b) Stabilatore.

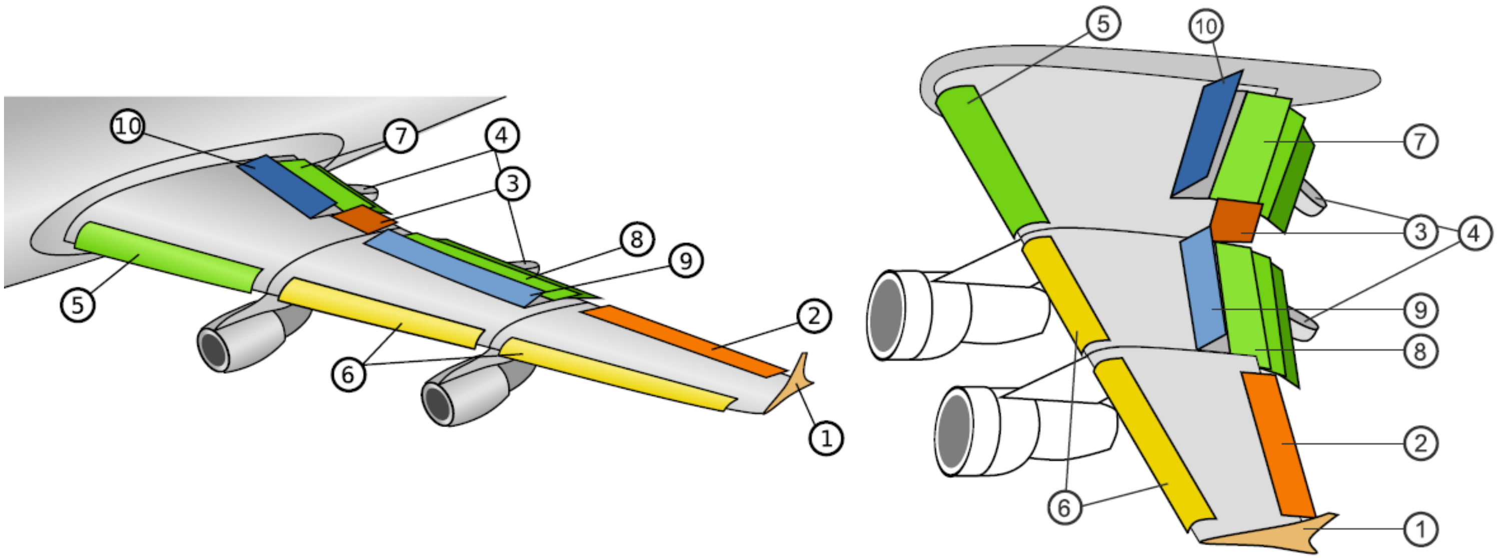
Figura 1.6 Tipici elementi funzionali di impennaggi di coda tradizionali.

Alettoni, spoiler, …

(a) Alettone di un tipico velivolo dell'aviazione generale.

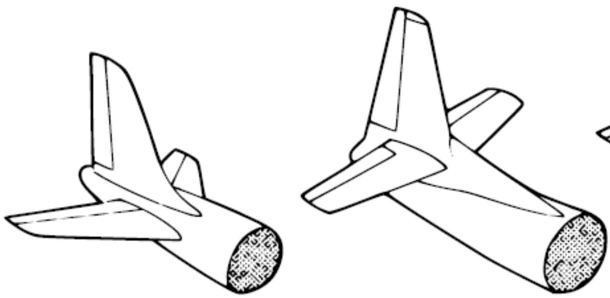


(b) Tipica struttura alare di un velivolo dell'aviazione generale.

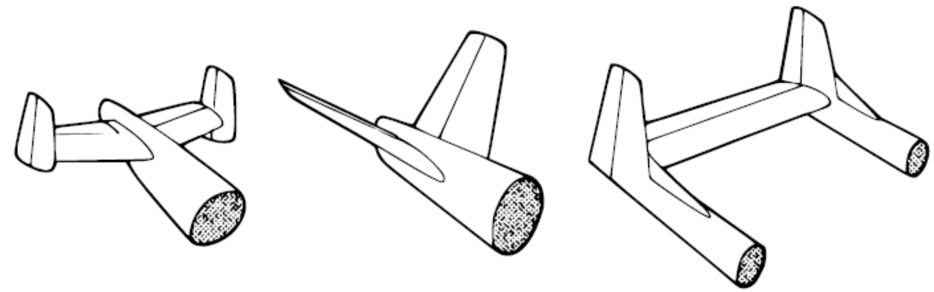


(c) Superfici di governo primarie e secondarie su un'ala di un velivolo da trasporto commerciale: ① *winglet*, ② alettone di bassa velocità, ③ alettone di alta velocità, ④ guide *flap*, ⑤ *flap* di tipo *Krüger*, ⑥ *slats*, ⑦ *slotted flaps* interni, ⑧ *slotted flaps* esterni, ⑨ *spoilers*, ⑩ *spoilers*-aerofreni.

Tipi di impennaggi non convenzionali



(a) I tipi di impennaggio di coda tradizionali.



(b) Alcuni tipi di impennaggio di coda non tradizionali.

(c) Il Beech 35 *Bonanza*, dotato di con impennaggio di coda a "V".

Figura 1.9 Esempi di configurazioni architettoniche tradizionali e non tradizionali degli impennaggi di coda.

Momenti aerodinamici di controllo

$$\Delta\mathcal{M} = \left.\frac{\partial\mathcal{M}}{\partial\delta_e}\right|_{\bar{\delta}_e} \Delta\delta_e = \mathcal{M}_{\delta_e}\,\Delta\delta_e$$

$$\Delta\mathcal{L} = \left.\frac{\partial\mathcal{L}}{\partial\delta_a}\right|_{\bar{\delta}_a} \Delta\delta_a = \mathcal{L}_{\delta_a}\,\Delta\delta_a$$

$$\begin{aligned}\Delta\mathcal{L} &= \left.\frac{\partial\mathcal{L}}{\partial\delta_a}\right|_{\bar{\delta}_a,\bar{\delta}_r} \Delta\delta_a + \left.\frac{\partial\mathcal{L}}{\partial\delta_r}\right|_{\bar{\delta}_a,\bar{\delta}_r} \Delta\delta_r \\ &= \mathcal{L}_{\delta_a}\,\Delta\delta_a + \mathcal{L}_{\delta_r}\,\Delta\delta_r\end{aligned}$$

$$\begin{aligned}\Delta\mathcal{N} &= \left.\frac{\partial\mathcal{N}}{\partial\delta_a}\right|_{\bar{\delta}_a,\bar{\delta}_r} \Delta\delta_a + \left.\frac{\partial\mathcal{N}}{\partial\delta_r}\right|_{\bar{\delta}_a,\bar{\delta}_r} \Delta\delta_r \\ &= \mathcal{N}_{\delta_a}\,\Delta\delta_a + \mathcal{N}_{\delta_r}\,\Delta\delta_r\end{aligned}$$

Coefficienti di forza e momento

$$C_X = \frac{X}{\bar{q}S} \qquad C_Y = \frac{Y}{\bar{q}S} \qquad C_Z = \frac{Z}{\bar{q}S}$$

$$C_{\mathcal{L}} = \frac{\mathcal{L}}{\bar{q}Sb} \qquad C_{\mathcal{M}} = \frac{\mathcal{M}}{\bar{q}Sc} \qquad C_{\mathcal{N}} = \frac{\mathcal{N}}{\bar{q}Sb}$$

$\bar{q}$ = pressione dinamica $= \frac{1}{2}\rho(u^2 + v^2 + w^2) = \frac{1}{2}\gamma\, p\, M^2$, detta anche q_∞,

ρ = densità dell'aria alla quota effettiva di volo,

p = pressione statica alla quota effettiva di volo,

M = numero di Mach di volo,

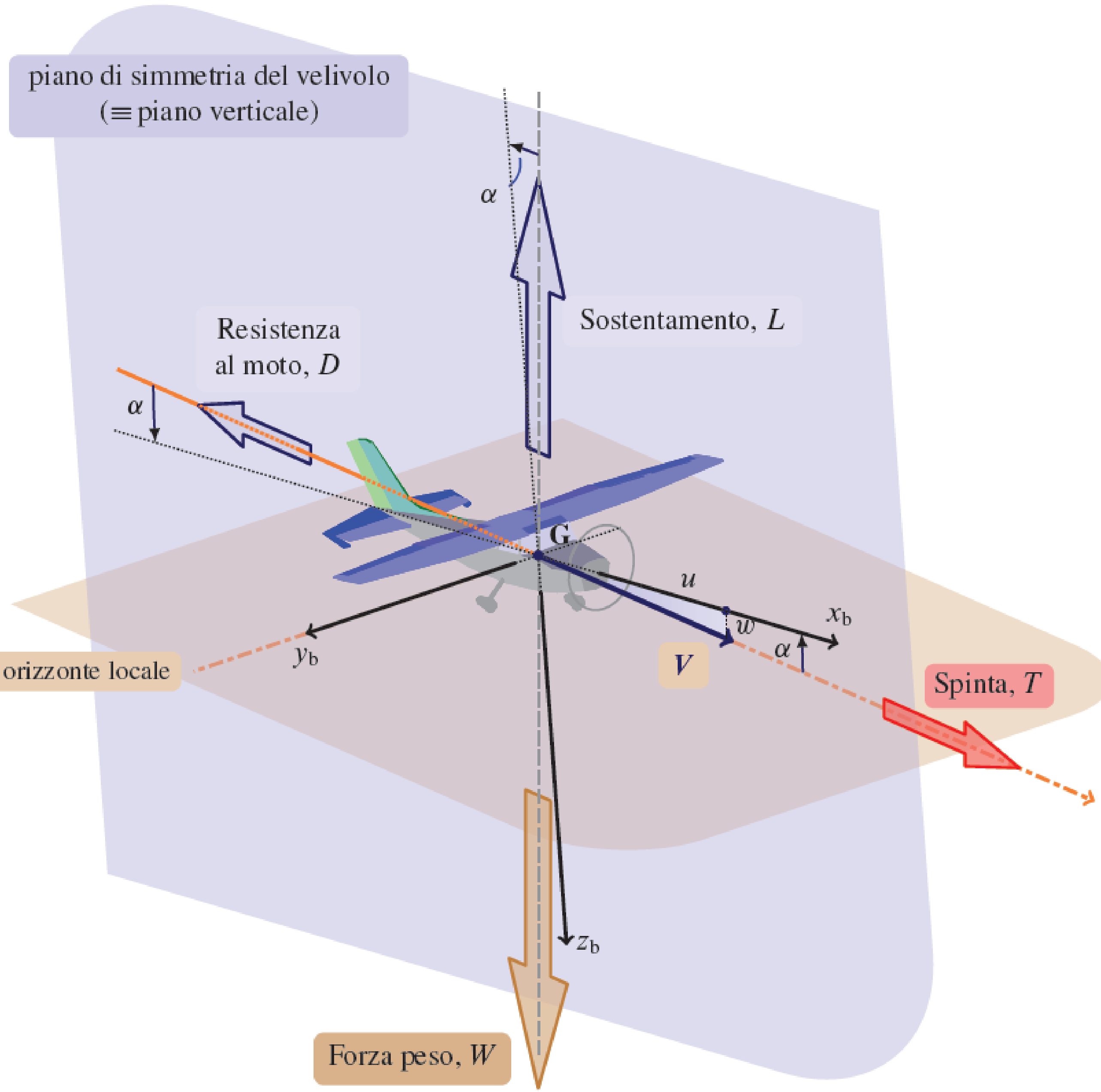
γ = rapporto dei calori specifici dell'aria ($= 1{,}4$),

S = superficie di riferimento, tipicamente la superficie della forma in pianta dell'ala,

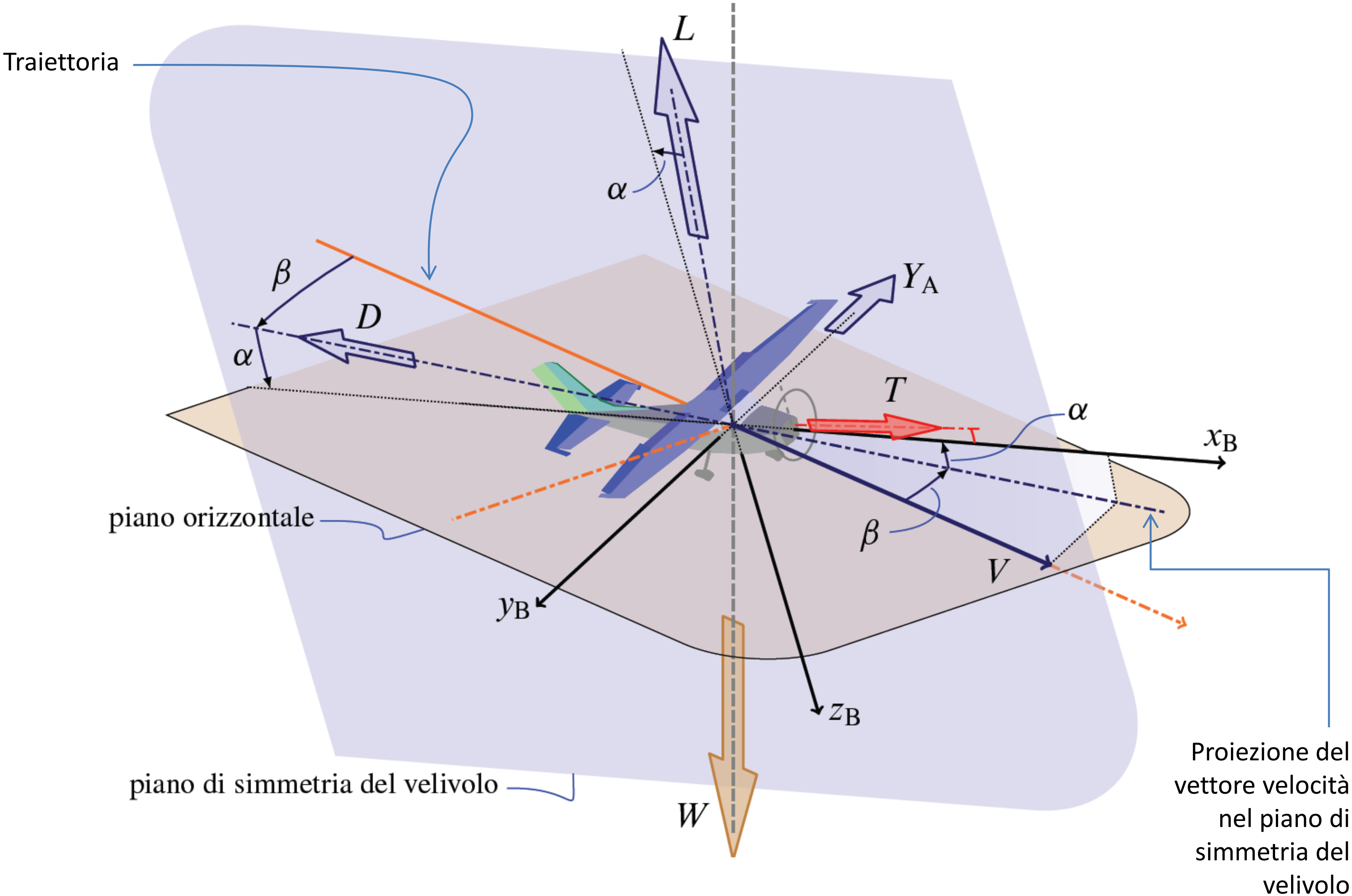
b = apertura alare di riferimento,

c = corda alare di riferimento, tipicamente la corda media aerodinamica dell'ala.

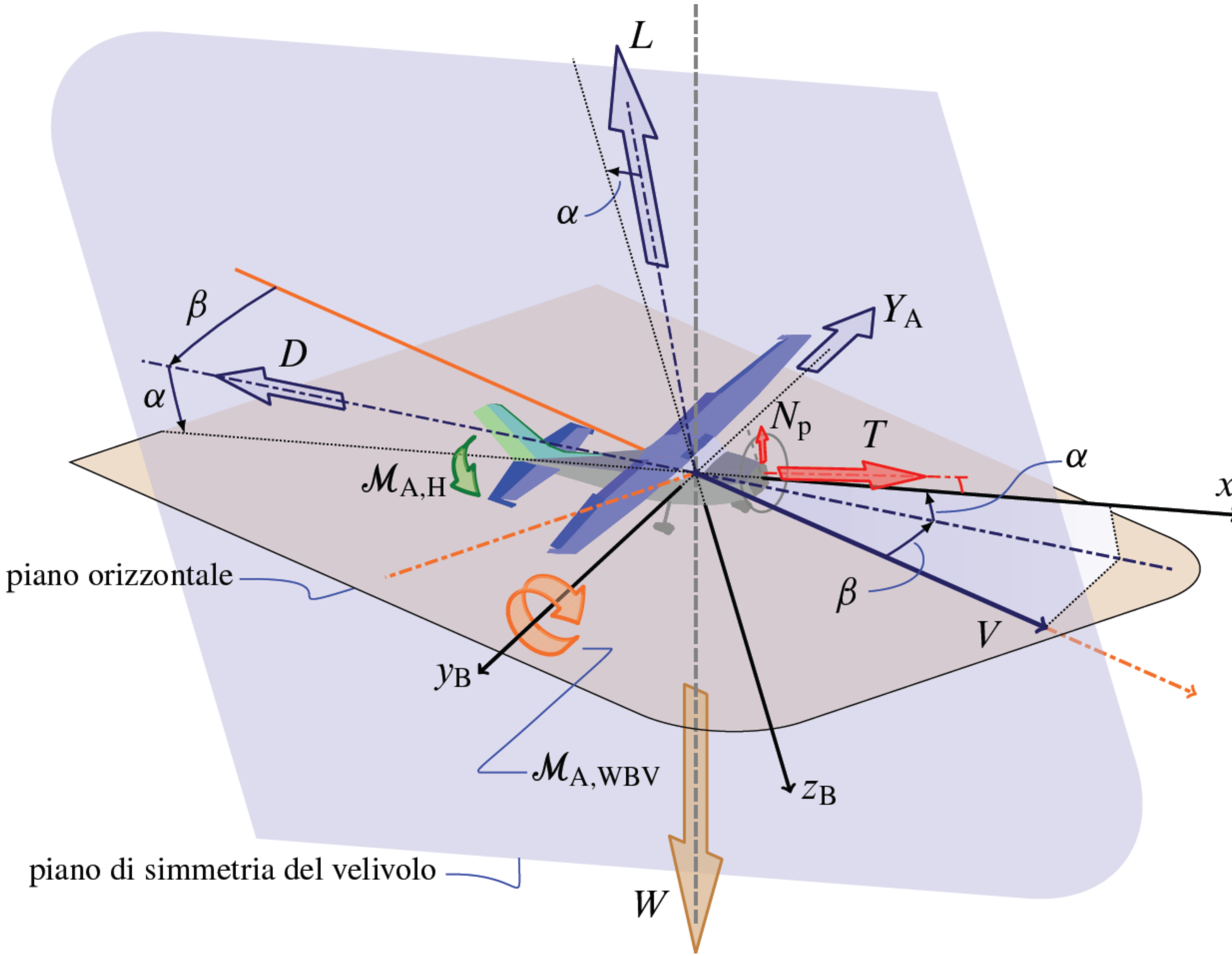
Le 4 forze della Meccanica del volo



Crabbing (volo asimmetrico)



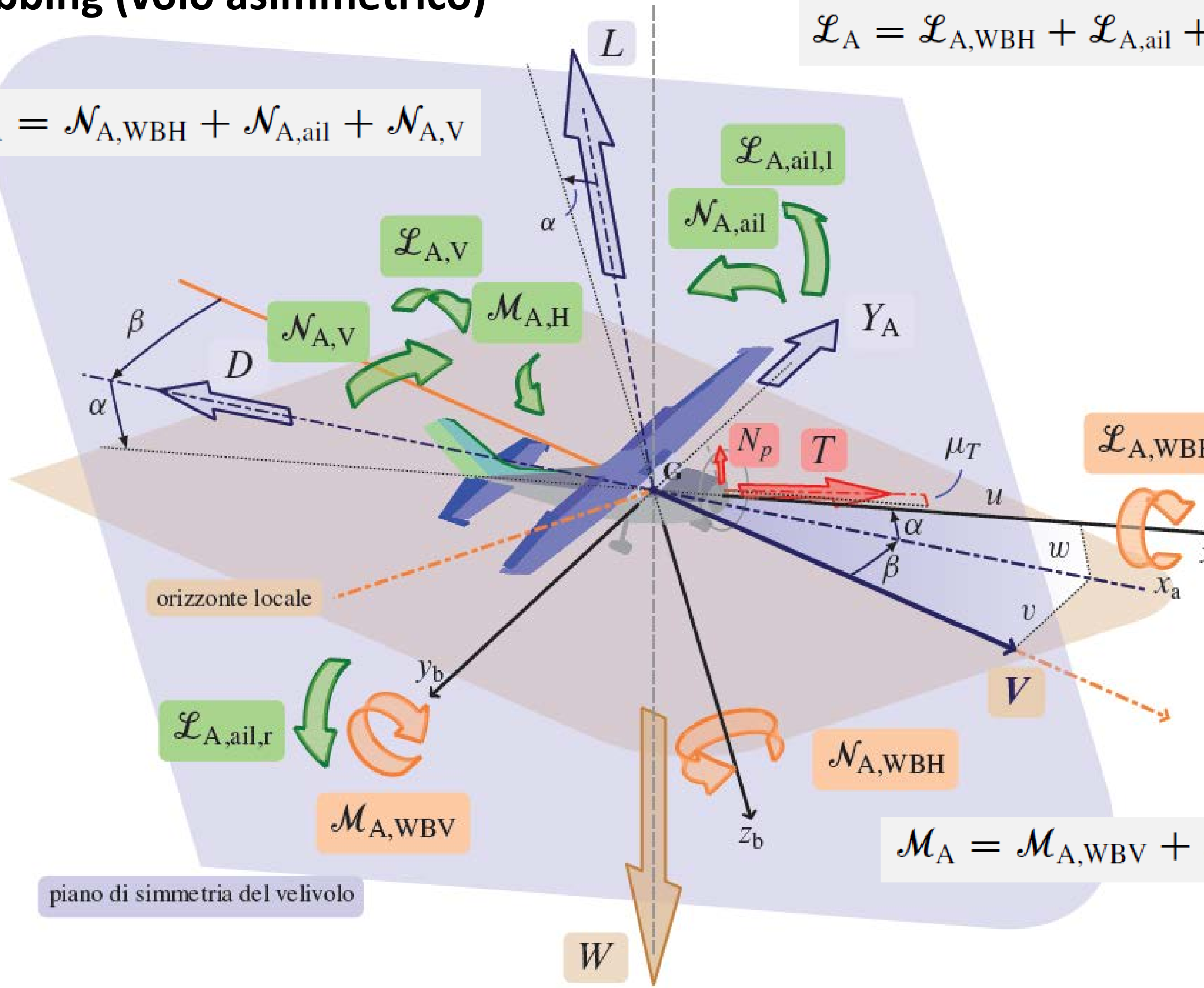
Crabbing (volo asimmetrico)



Crabbing (volo asimmetrico)

$$\mathcal{L}_{A} = \mathcal{L}_{A,WBH} + \mathcal{L}_{A,ail} + \mathcal{L}_{A,V}$$

$$\mathcal{N}_{A} = \mathcal{N}_{A,WBH} + \mathcal{N}_{A,ail} + \mathcal{N}_{A,V}$$



$$\mathcal{M}_{A} = \mathcal{M}_{A,WBV} + \mathcal{M}_{A,H}$$

Crabbing (volo asimmetrico)

Riduzione dei sistemi di forze

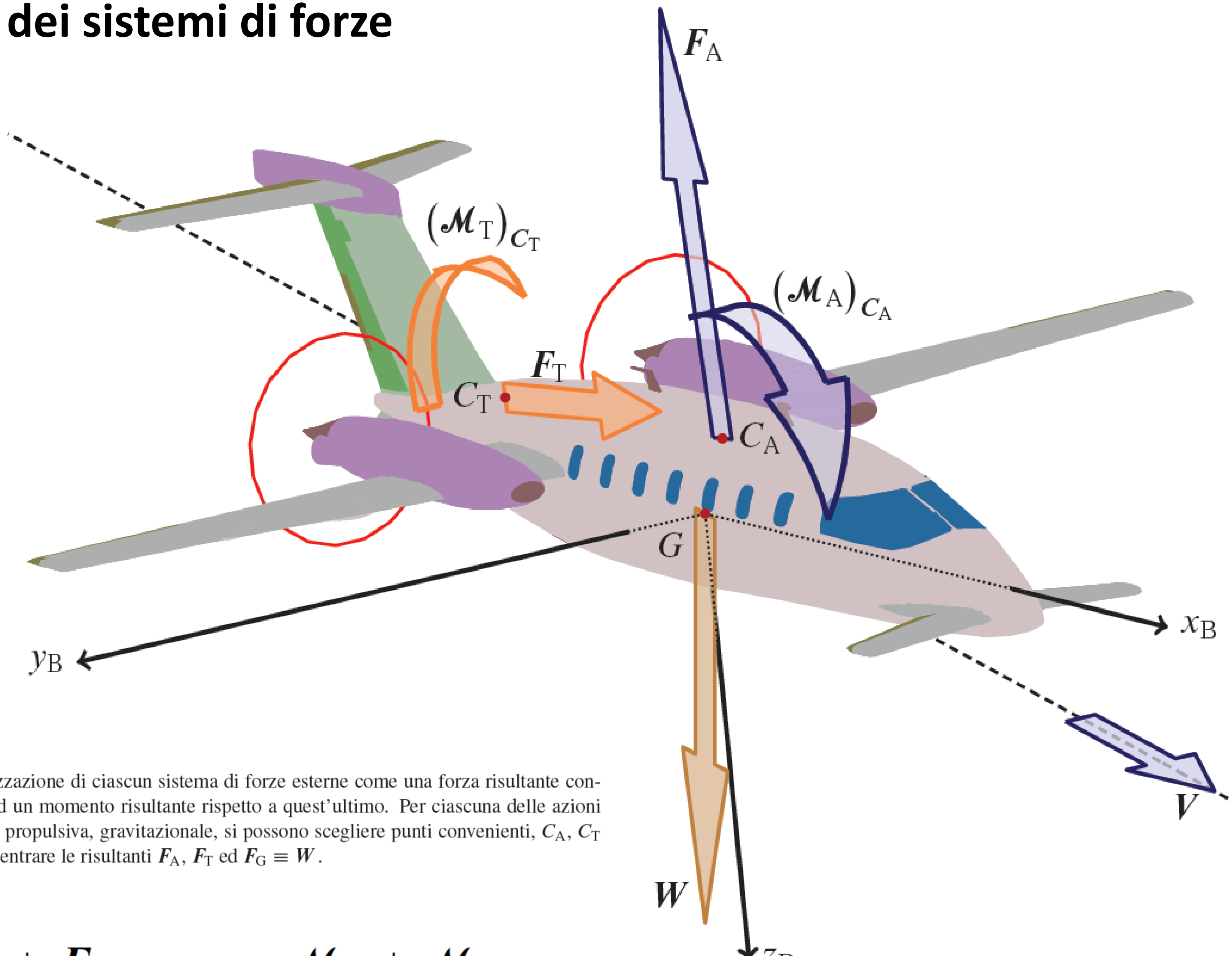


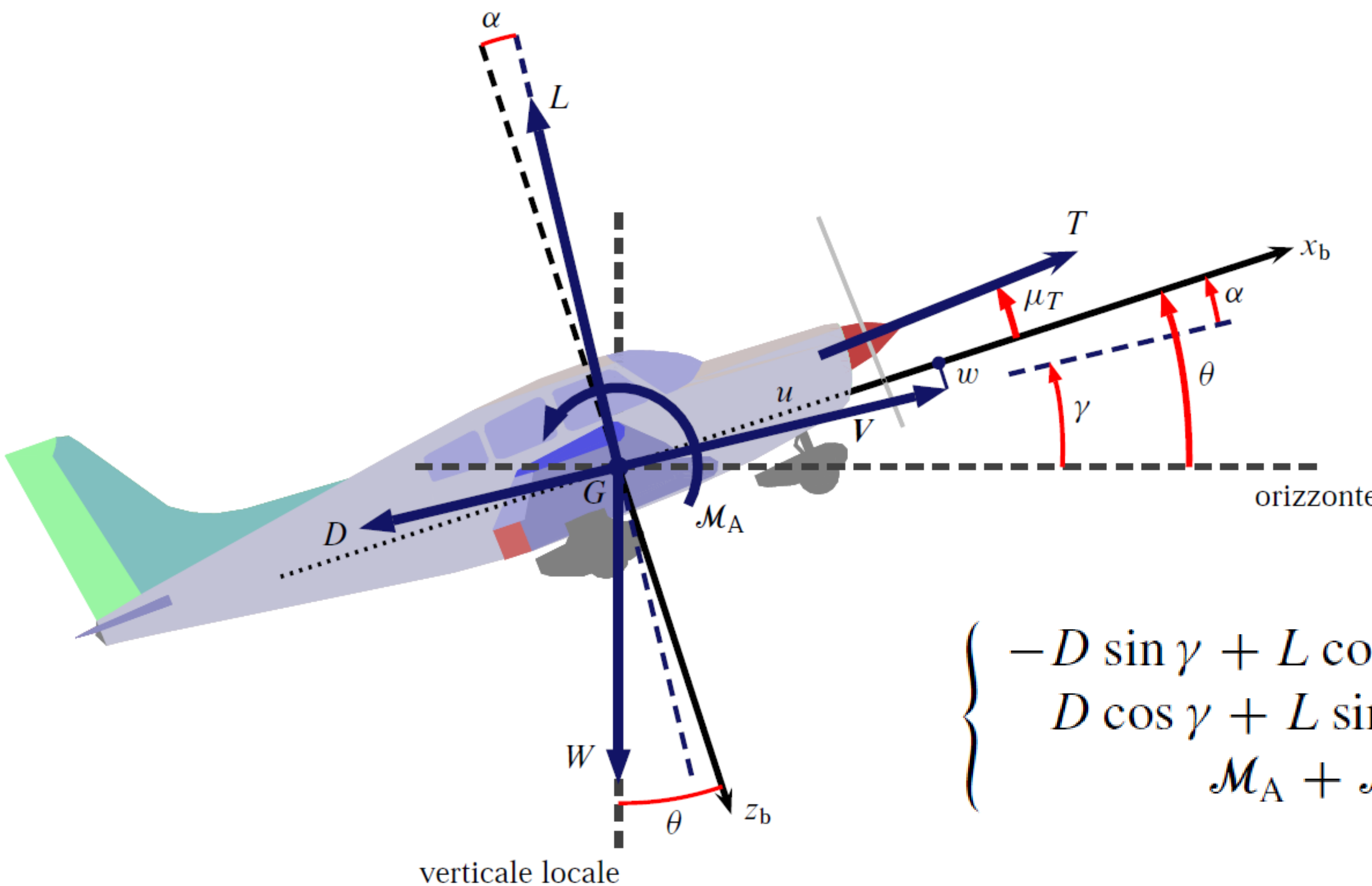
Figura 1.13 Schematizzazione di ciascun sistema di forze esterne come una forza risultante concentrata in un punto ed un momento risultante rispetto a quest'ultimo. Per ciascuna delle azioni esterne, aerodinamica, propulsiva, gravitazionale, si possono scegliere punti convenienti, C_A, C_T e $C_G \equiv G$, in cui concentrare le risultanti $\boldsymbol{F}_A$, $\boldsymbol{F}_T$ ed $\boldsymbol{F}_G \equiv \boldsymbol{W}$.

$$\boldsymbol{F}_A + \boldsymbol{F}_T + \boldsymbol{F}_G \qquad \mathcal{M}_A + \mathcal{M}_T$$

Volo equilibrato

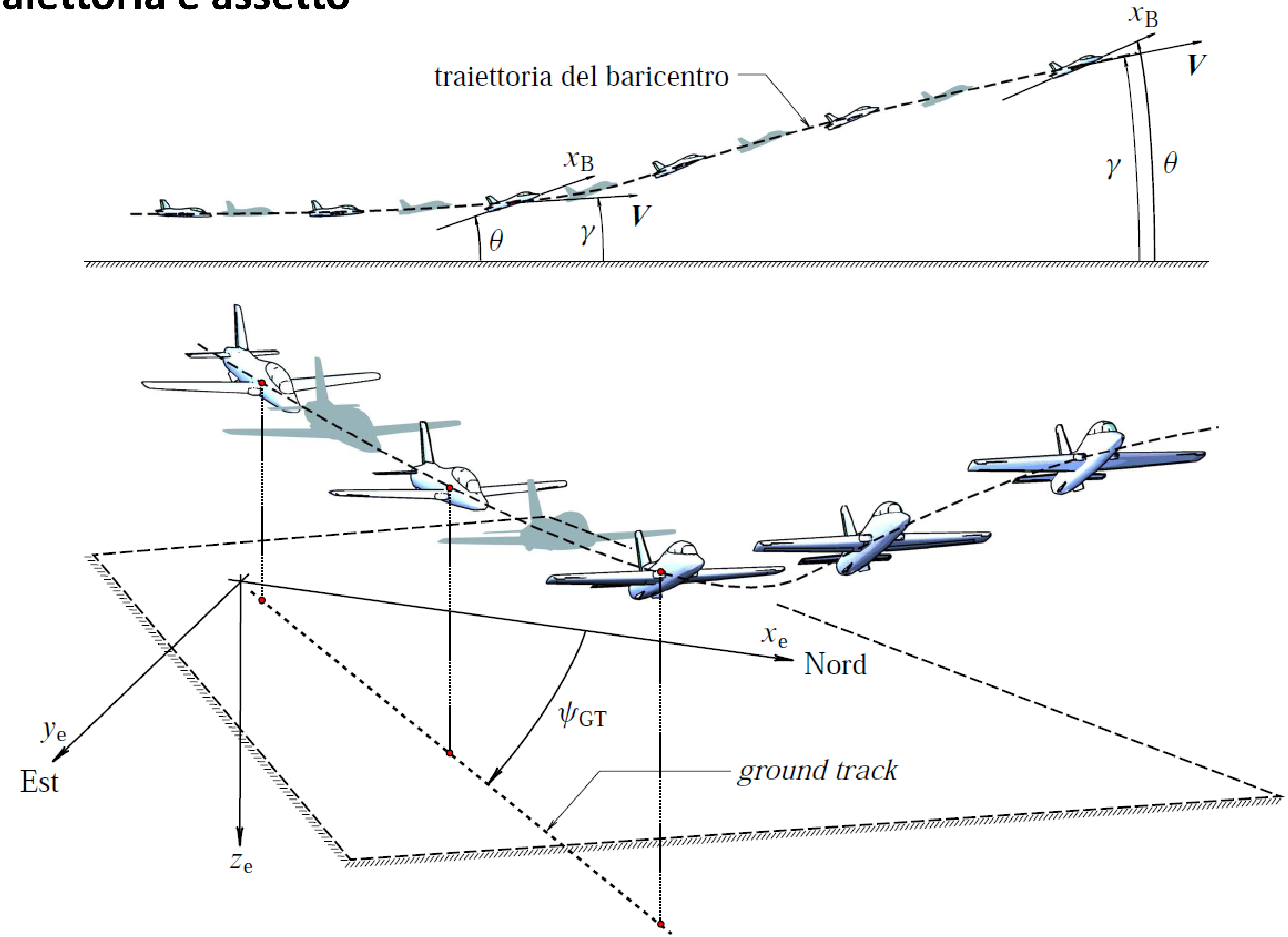
$$0 = \left(X_{\text{G}} + X_{\text{A}} + X_{\text{T}} \right) \boldsymbol{i} + \left(Y_{\text{G}} + Y_{\text{A}} + Y_{\text{T}} \right) \boldsymbol{j} + \left(Z_{\text{G}} + Z_{\text{A}} + Z_{\text{T}} \right) \boldsymbol{k}$$

$$\mathscr{L}_{\text{A}} + \mathscr{L}_{\text{T}} = 0\,, \quad \mathscr{M}_{\text{A}} + \mathscr{M}_{\text{T}} = 0\,, \quad \mathscr{N}_{\text{A}} + \mathscr{N}_{\text{T}} = 0$$



$$\begin{cases} -D \sin\gamma + L \cos\gamma &= W \\ D \cos\gamma + L \sin\gamma &= T \\ \mathscr{M}_{\text{A}} + \mathscr{M}_{\text{T}} &= 0 \end{cases}$$

Traiettoria e assetto



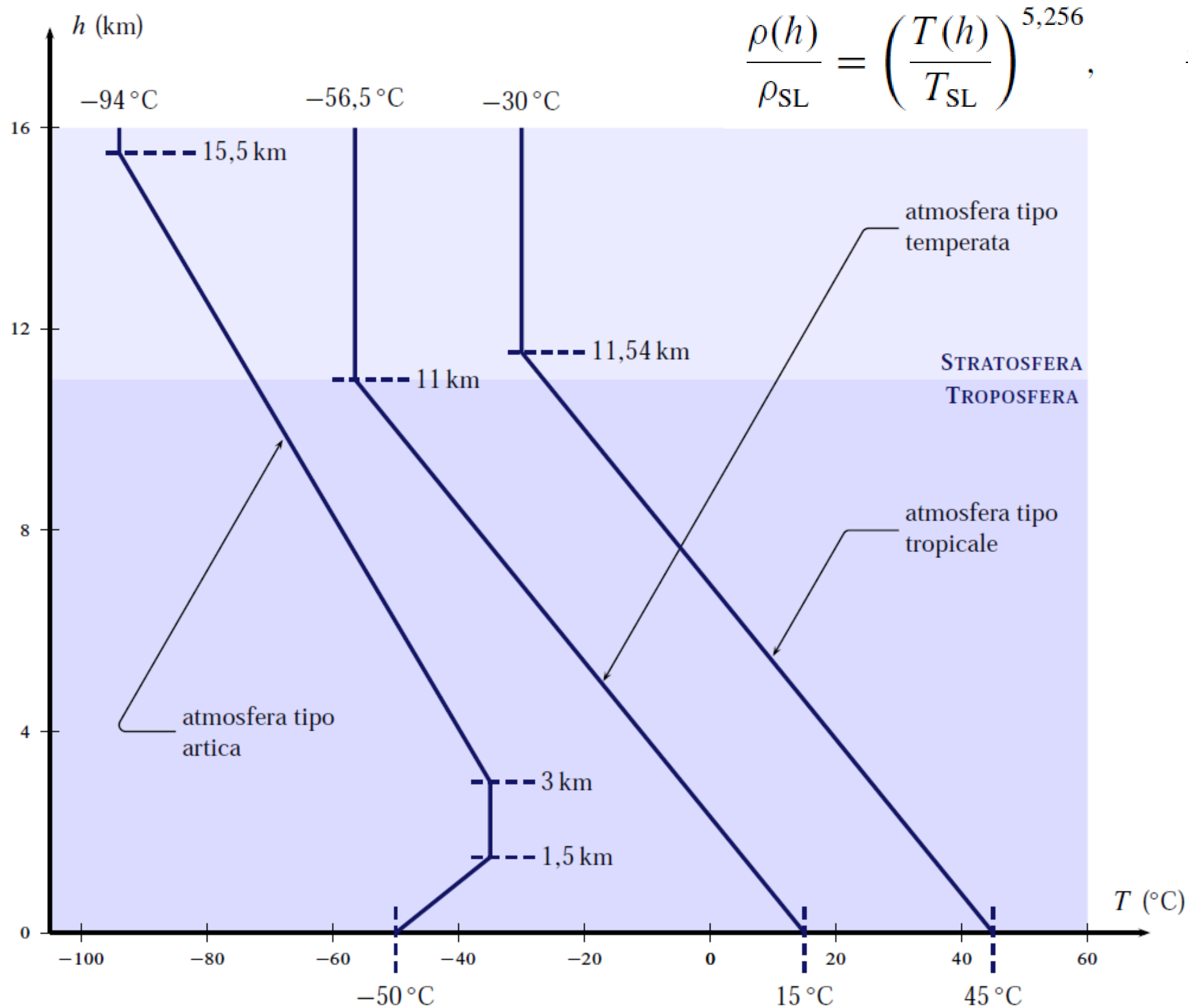
Concetti introduttivi

Concetti introduttivi

Modello di atmosfera, ISA

$$T(h) = T_{SL} - T_h\, h = 288 - 0{,}0065\, h$$

$$\frac{\rho(h)}{\rho_{SL}} = \left(\frac{T(h)}{T_{SL}}\right)^{5{,}256}, \qquad \frac{p(h)}{p_{SL}} = \left(\frac{T(h)}{T_{SL}}\right)^{4{,}256}$$



Modello di atmosfera, ISA

Tabella 1.1 Principali proprietà dell'atmosfera al livello del mare (*sea level*, SL) secondo il modello di atmosfera *standard* dell'*ICAO International Standard Atmosphere* (ISA), per una latitudine di 45°.

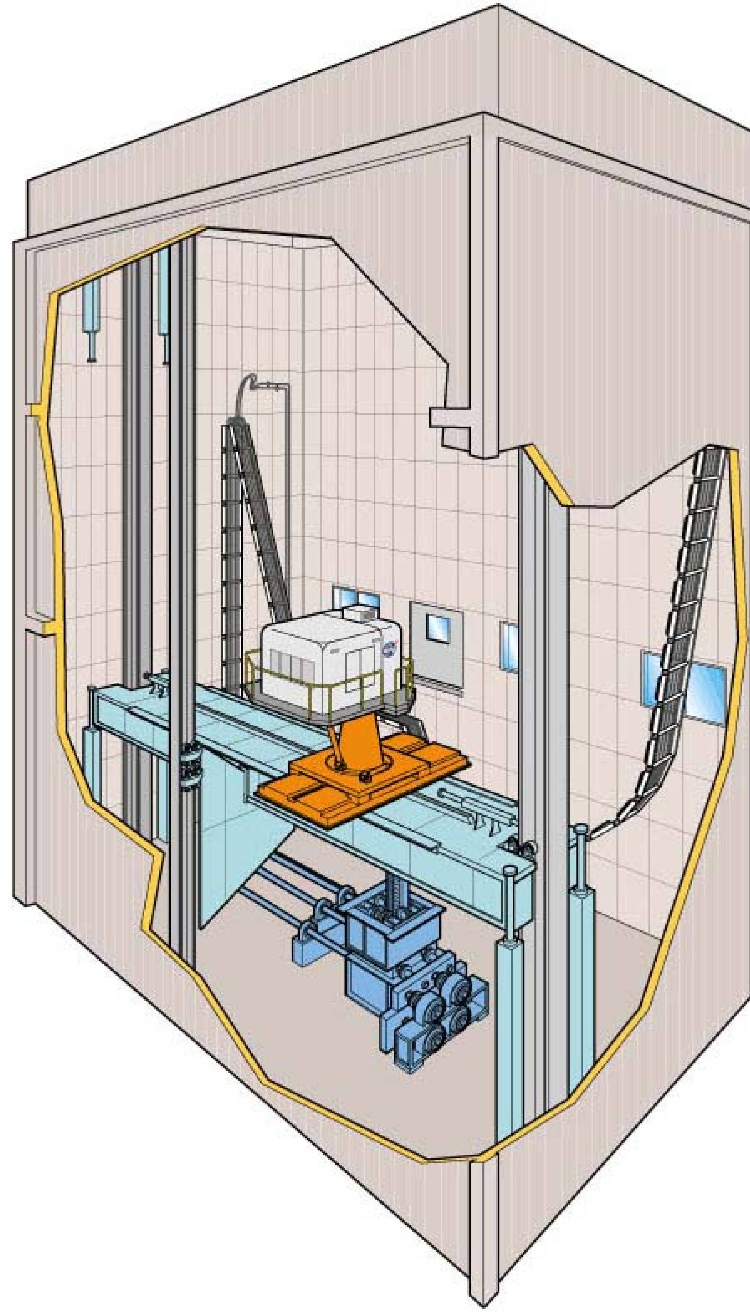
Grandezza	Sistema metrico	Sistema inglese
Pressione, p_{SL}	$1013{,}25\ \mathrm{N\,m^{-2}}$	$2116{,}2\ \mathrm{lb}$
Densità, ρ_{SL}	$1{,}225\ \mathrm{kg\,m^{-3}}$	$0{,}002\,377\ \mathrm{slug\,ft^{-3}}$
Temperatura, T_{SL}	$15{,}0\ ^\circ\mathrm{C}$	$518{,}67\ ^\circ\mathrm{R}$ $59{,}0\ ^\circ\mathrm{F}$
Velocità del suono, a_{SL}	$340{,}3\ \mathrm{m\,s^{-1}}$ $1225\ \mathrm{km\,h^{-1}}$	$116{,}4\ \mathrm{ft\,s^{-1}}$
Viscosità dinamica, μ_{SL}	$5{,}7571 \cdot 10^{-9}\ \mathrm{N\,s\,m^{-2}}$	$3{,}7373 \cdot 10^{-7}\ \mathrm{lb\,s\,ft^{-2}}$
Gradiente[a] termico verticale, $\left(\mathrm{d}T/\mathrm{d}z_e\right)_{SL}$	$6{,}5 \cdot 10^{-3}\ ^\circ\mathrm{C\,m^{-1}}$	
Gradiente[a] barico verticale, $\left(\mathrm{d}p/\mathrm{d}z_e\right)_{SL}$	$11{,}72\ \mathrm{Pa\,m^{-1}}$	

[a] Per definizione z_e decresce per quote crescenti: $h = -z_e$.

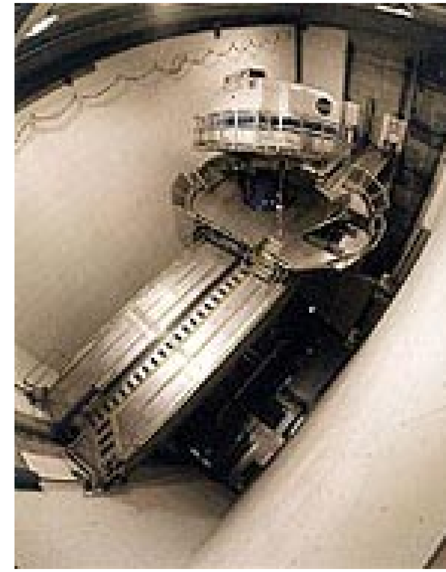
Concetti introduttivi

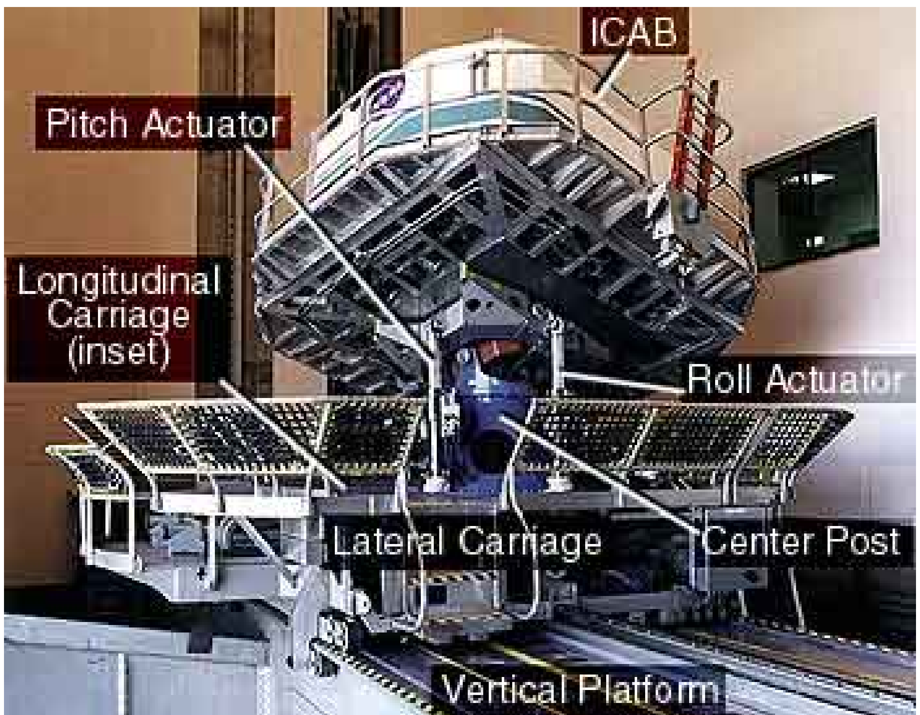
Volo in atmosfera

Volo simulato, NASA VMS



Simulatori di volo, NASA VMS





Interno cabina di un simulatore di volo, Level D

Interno cabina di un simulatore di volo, Level D

A380 simulator

Concetti introduttivi

Earth Centered Inertial, Earth Centered Earth Fixed

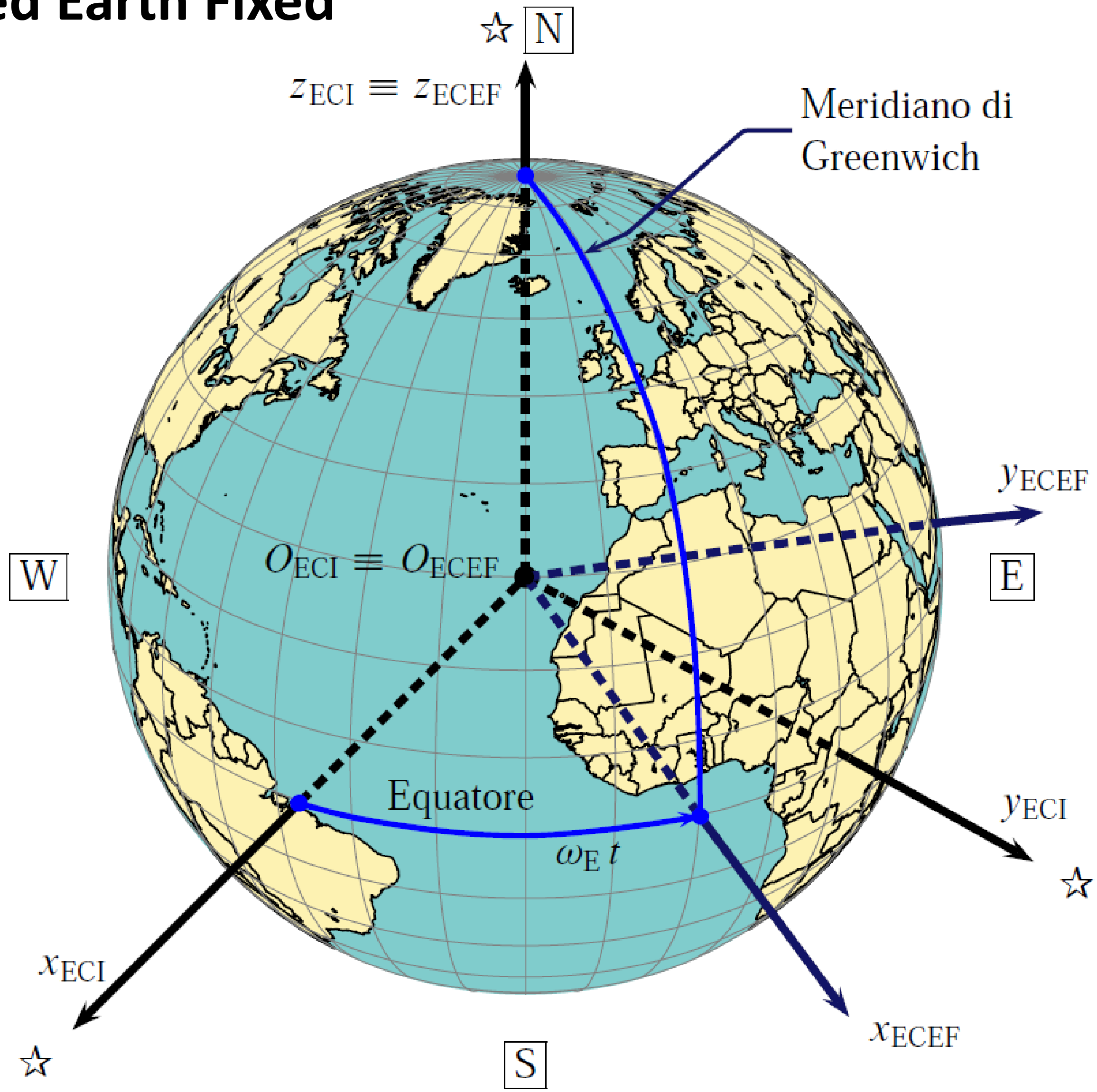


Figura 1.1 Riferimento inerziale $\mathcal{T}_{ECI}$ e riferimento solidale alla Terra $\mathcal{T}_{ECR}$.

Geodesia

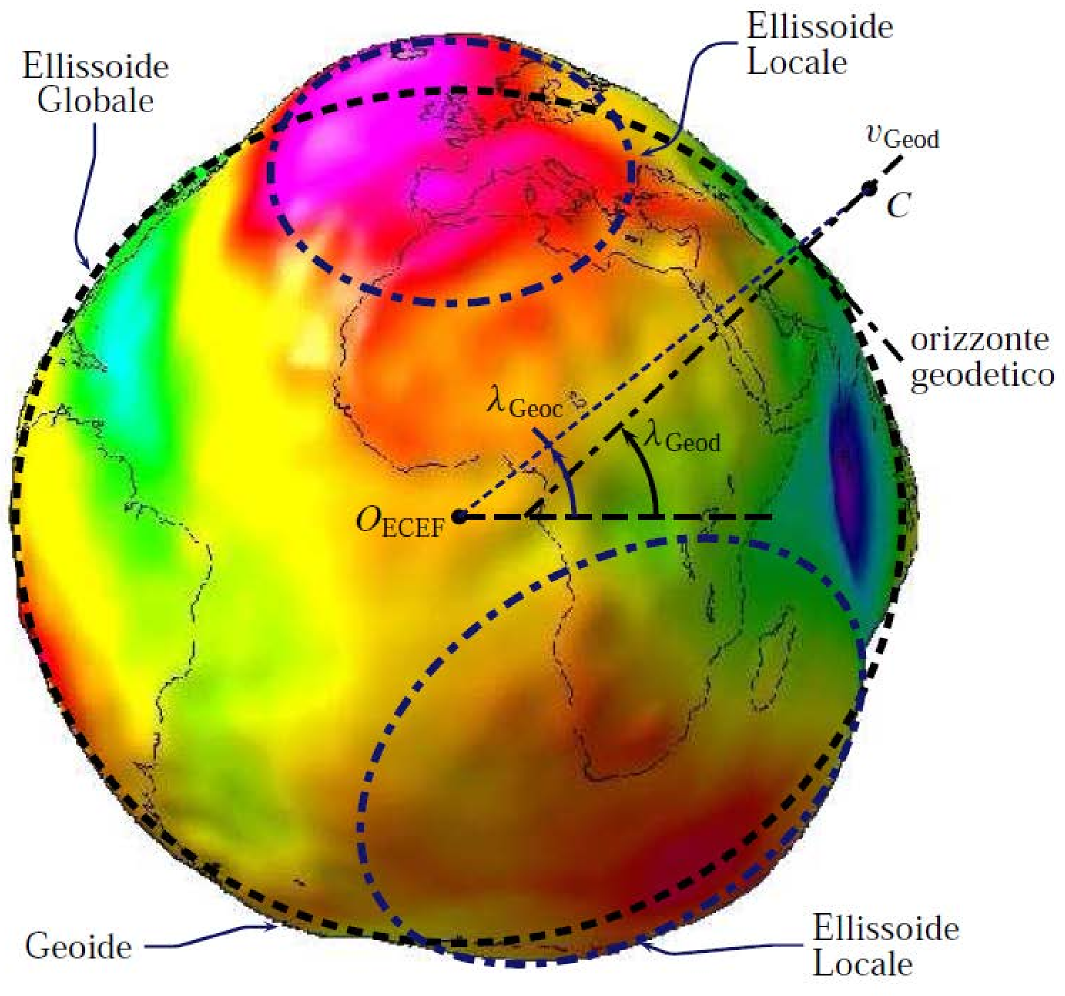


Figura 1.2 Geoide terrestre, ellissoide globale, ed ellissoidi locali. Nella rappresentazione tridimensionale i discostamenti dei punti del geoide dall'ellissoide globale sono amplificati di un fattore di ordine 10^5.

Modelli geodetici

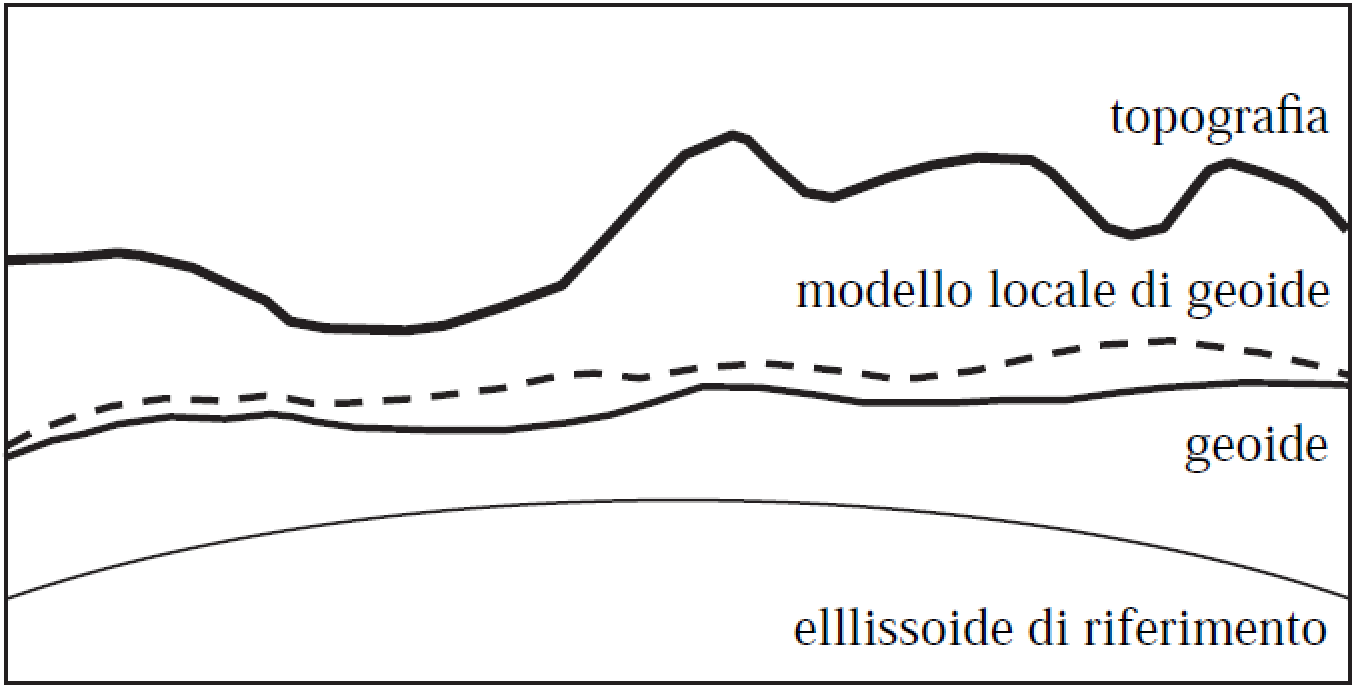


Figura 1.3 Profilo topografico e geoide globale. Spesso il geoide è approssimato localmente da un modello locale di geoide oppure da un ellissoide locale di riferimento.

Geoide, ellissoidi approssimanti

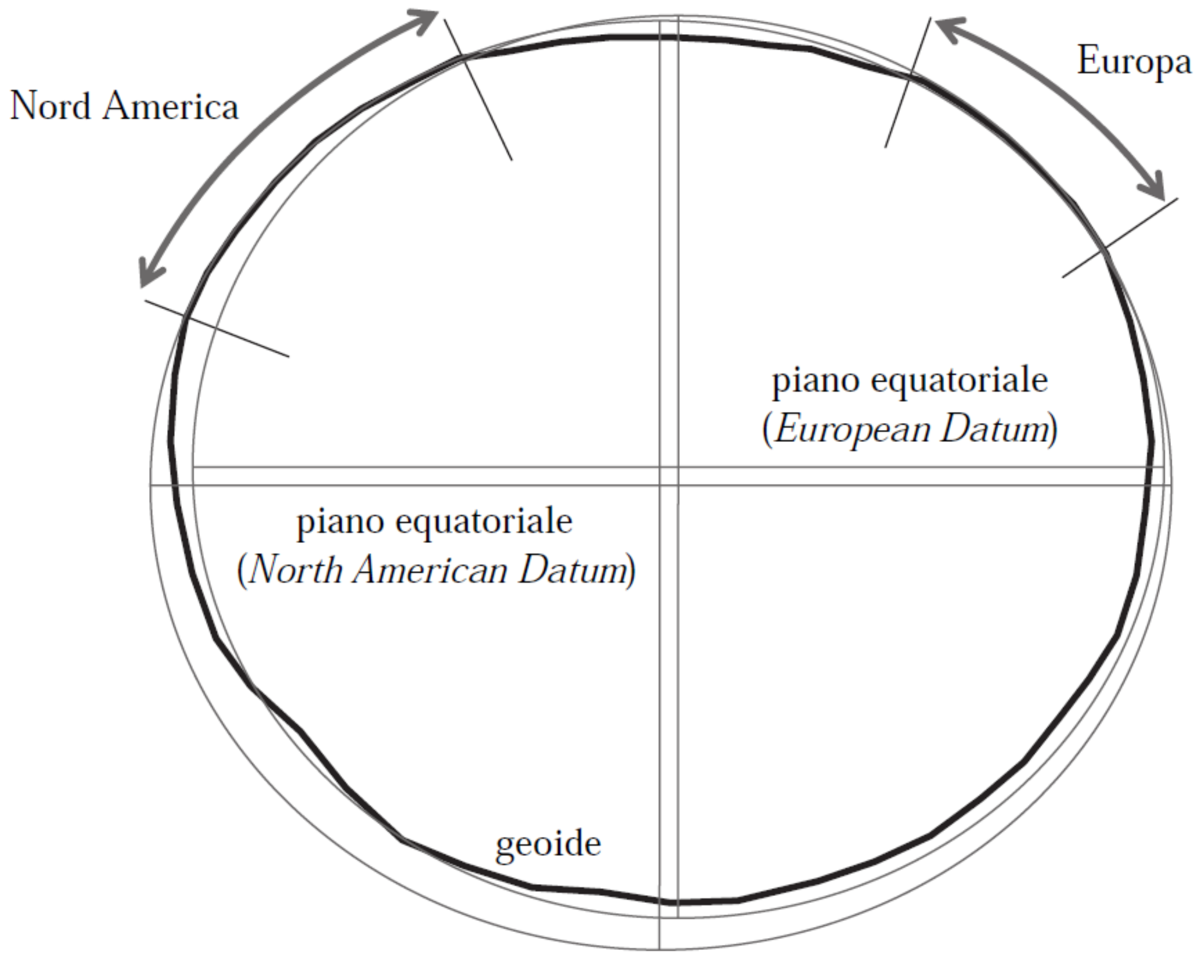


Figura 1.4 Profilo del geoide globale ed ellissoidi locali di riferimento.

Modelli geodetici, WGS84

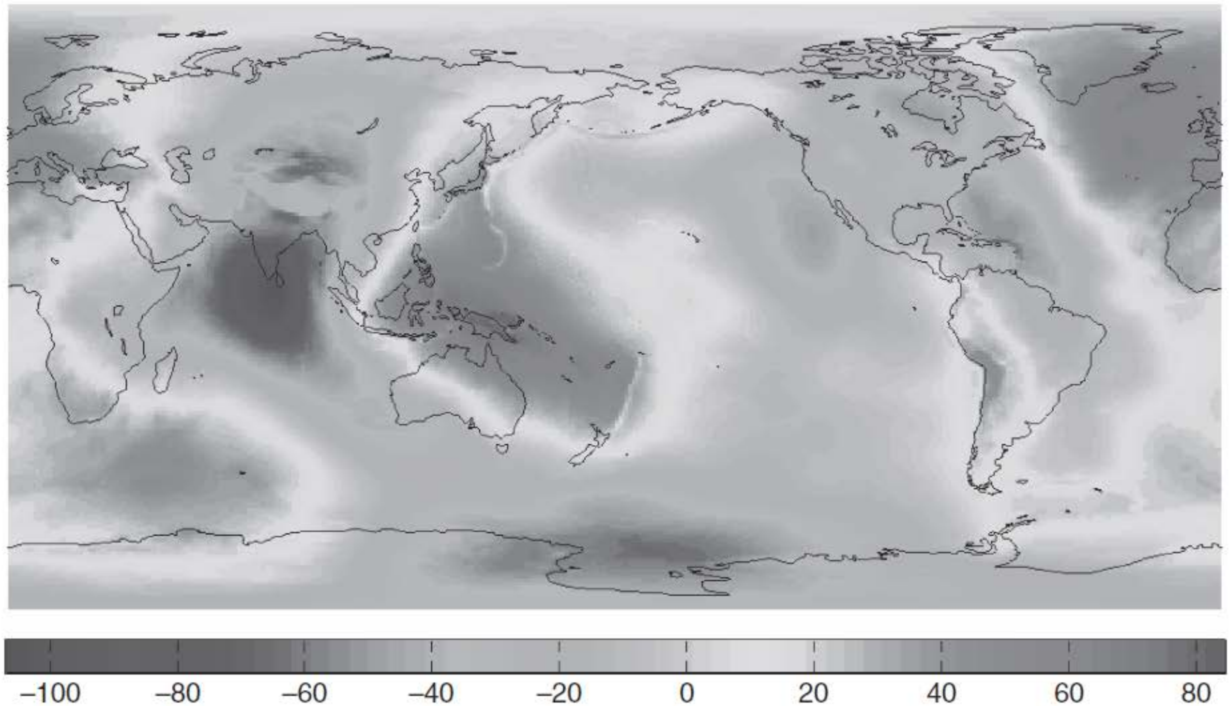


Figura 1.5 Discostamenti (in metri) del geoide dall'ellissoide di riferimento definito dal sistema WGS84.

Latitudine geodetica e geocentrica

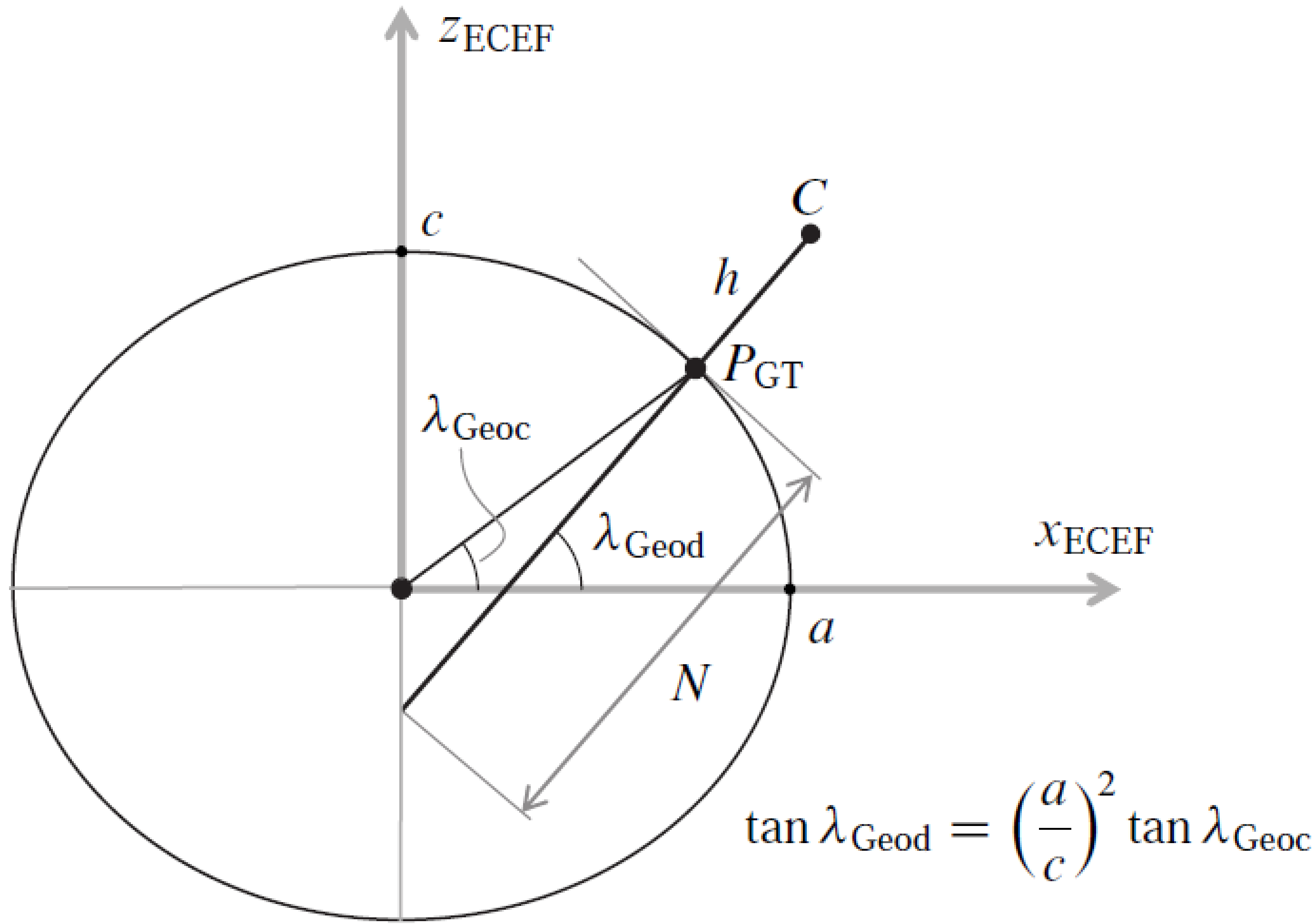


Figura 1.6 Latitudine geocentrica e geodetica.

Concetti introduttivi

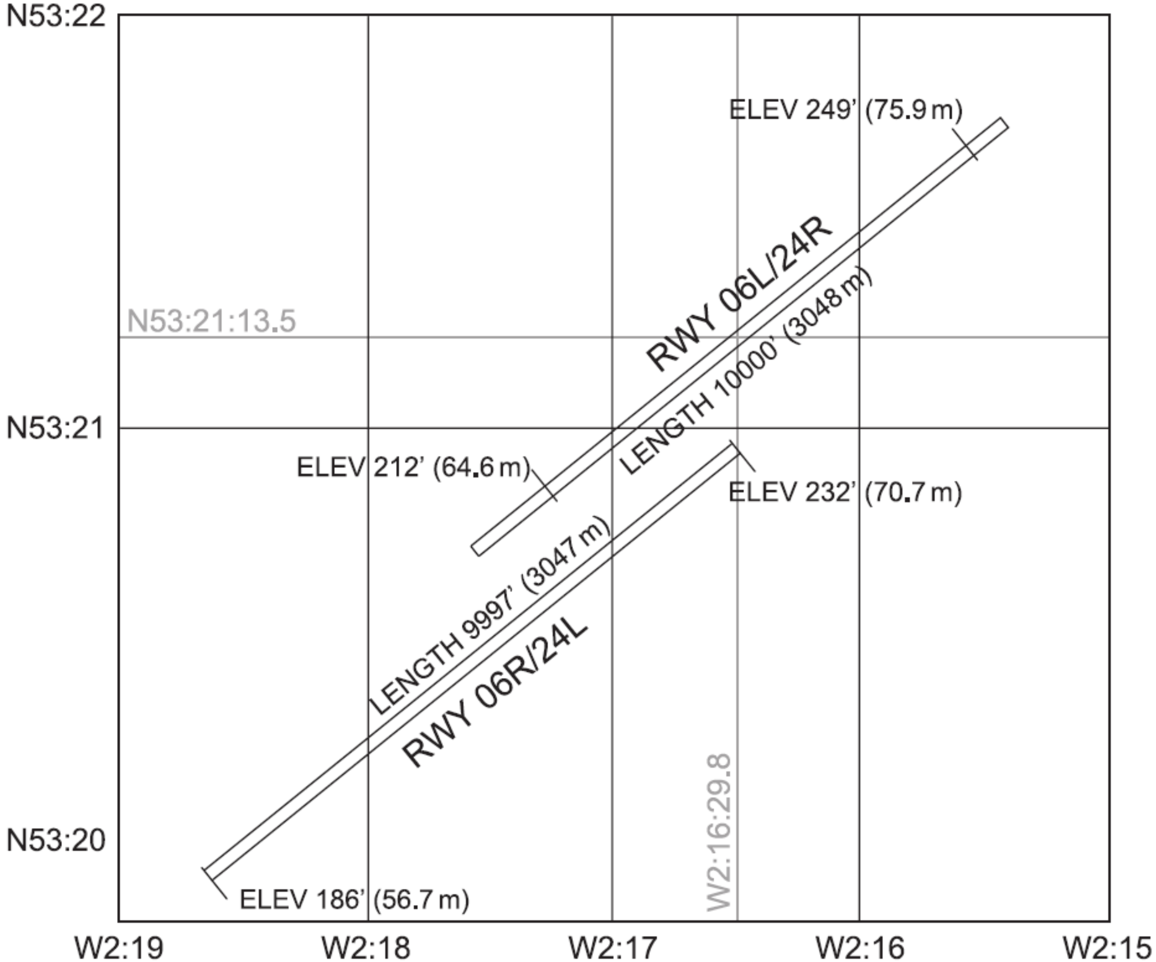


Figura 1.7 Collocazione delle piste dell'aeroporto di Manchester (sigla EGCC) ed elevazioni locali (riprodotta dal testo di Diston [8]). Elevazioni in piedi e in metri

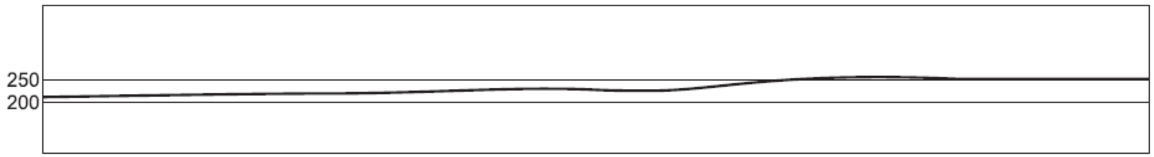


Figura 1.8 Profilo approssimativo della pista 06L/24R dell'aeroporto di Manchester (riprodotta dal testo di Diston [8]). Elevazioni in piedi.

Riferimenti tangenti, Local Vertical- -Local Horizontal

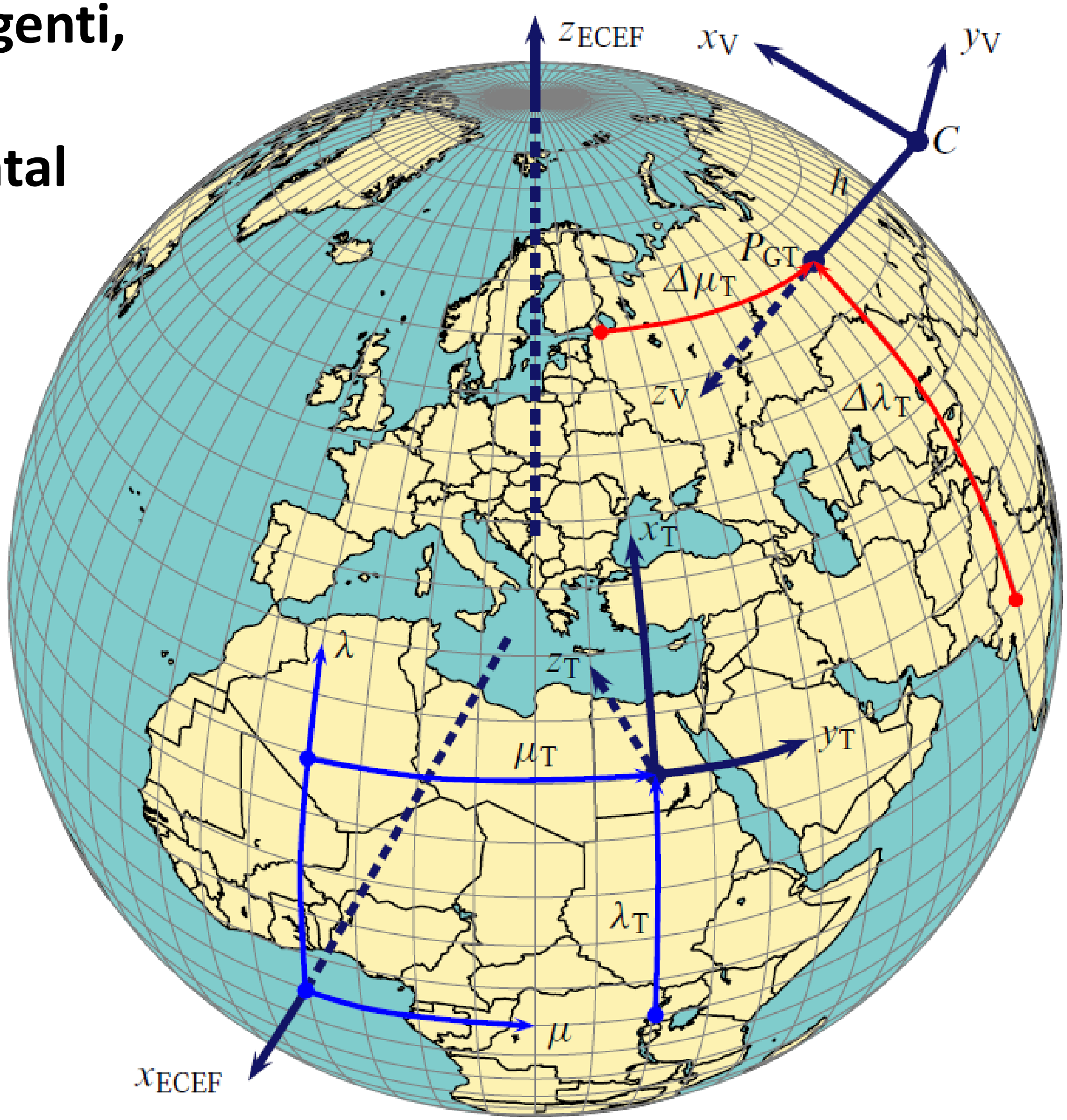


Figura 1.9 Terne di riferimento *Earth-Centered Earth-Fixed*, $\mathcal{T}_{ECEF}$, *Tangent*, $\mathcal{T}_T$, *Vehicle-Carried Vertical*, $\mathcal{T}_V$.

Earth frame, Flat Earth

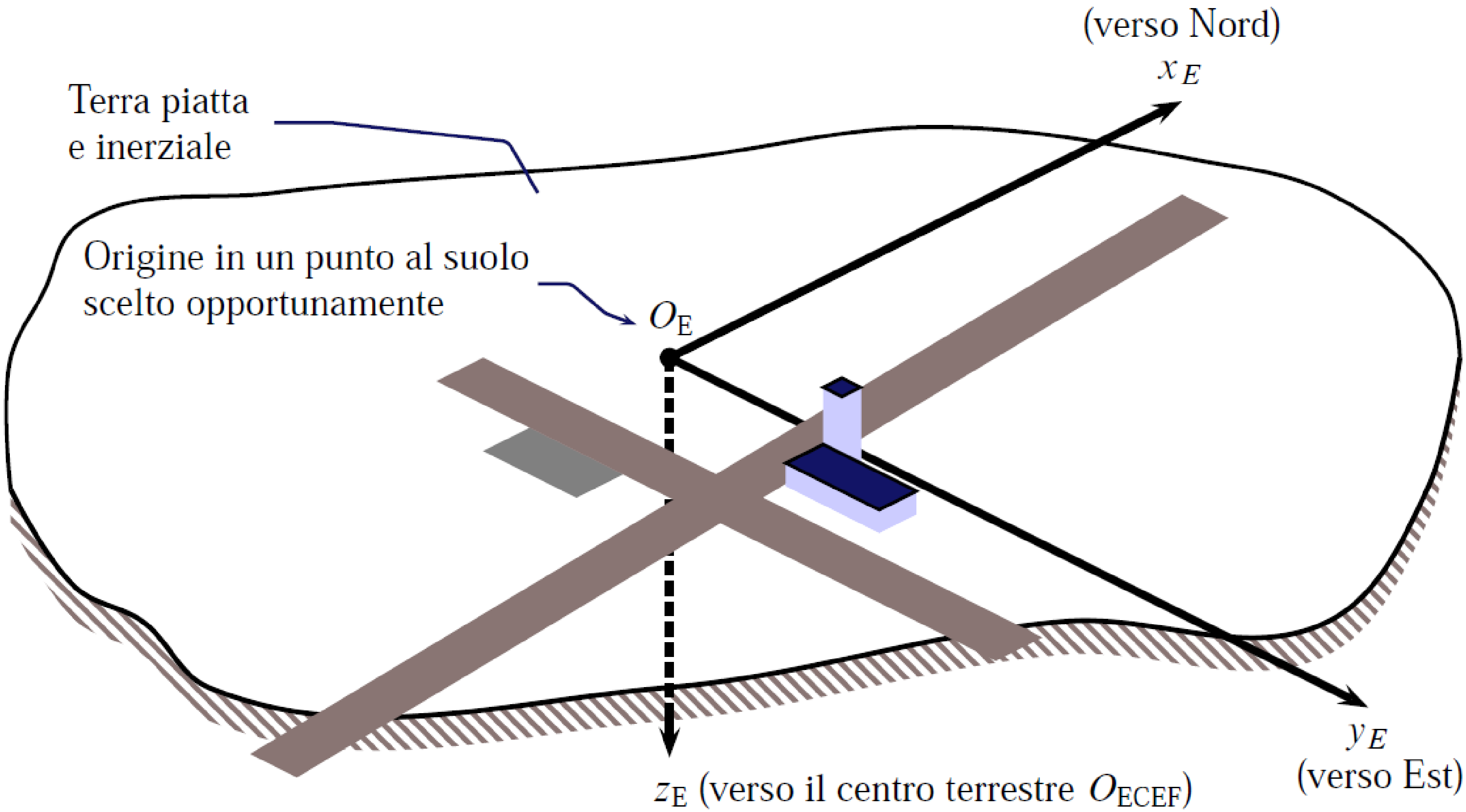


Figura 1.10 Riferimento fisso $\mathcal{T}_E \equiv \mathcal{T}_{LVLH}$ in ipotesi di Terra piatta ed inerziale.

Moti atmosferici

Figura 1.11 Terna di riferimento $\mathcal{T}_E$ e volo in prossimità del suolo. In generale, anche l'atmosfera è in moto rispetto alla Terra. Nell'illustrazione il velivolo trasla rispetto al suolo con velocità V e l'atmosferica trasla macroscopicamente con velocità V_{wind}.

Posizione e orientamento del velivolo rispetto alla terra

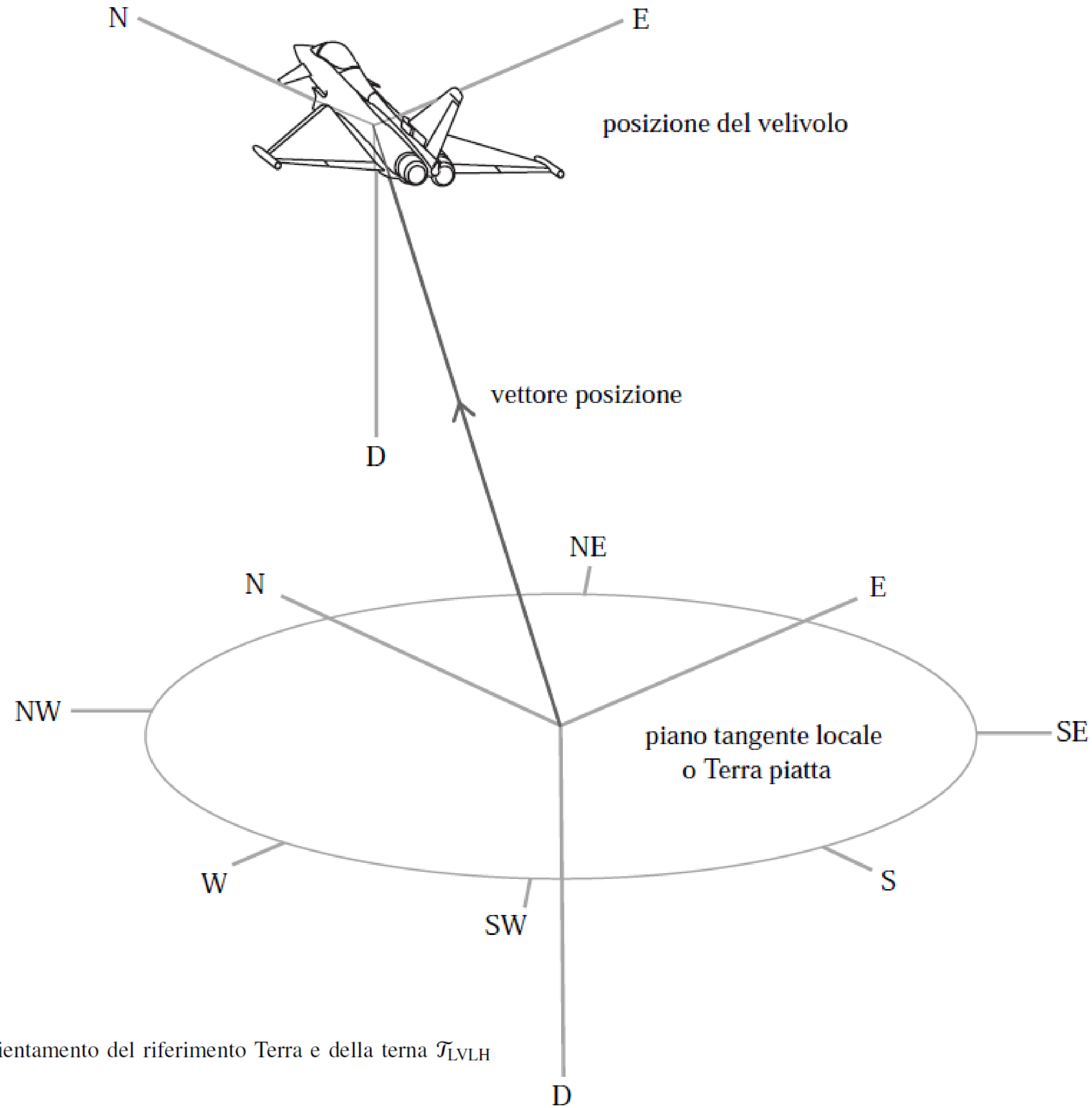


Figura 1.12 Posizione del velivolo rispetto alla Terra. Orientamento del riferimento Terra e della terna $\mathcal{T}_{\mathrm{LVLH}}$ secondo la convenzione *North-East-Down*.

Assi traiettoria e Wind axes

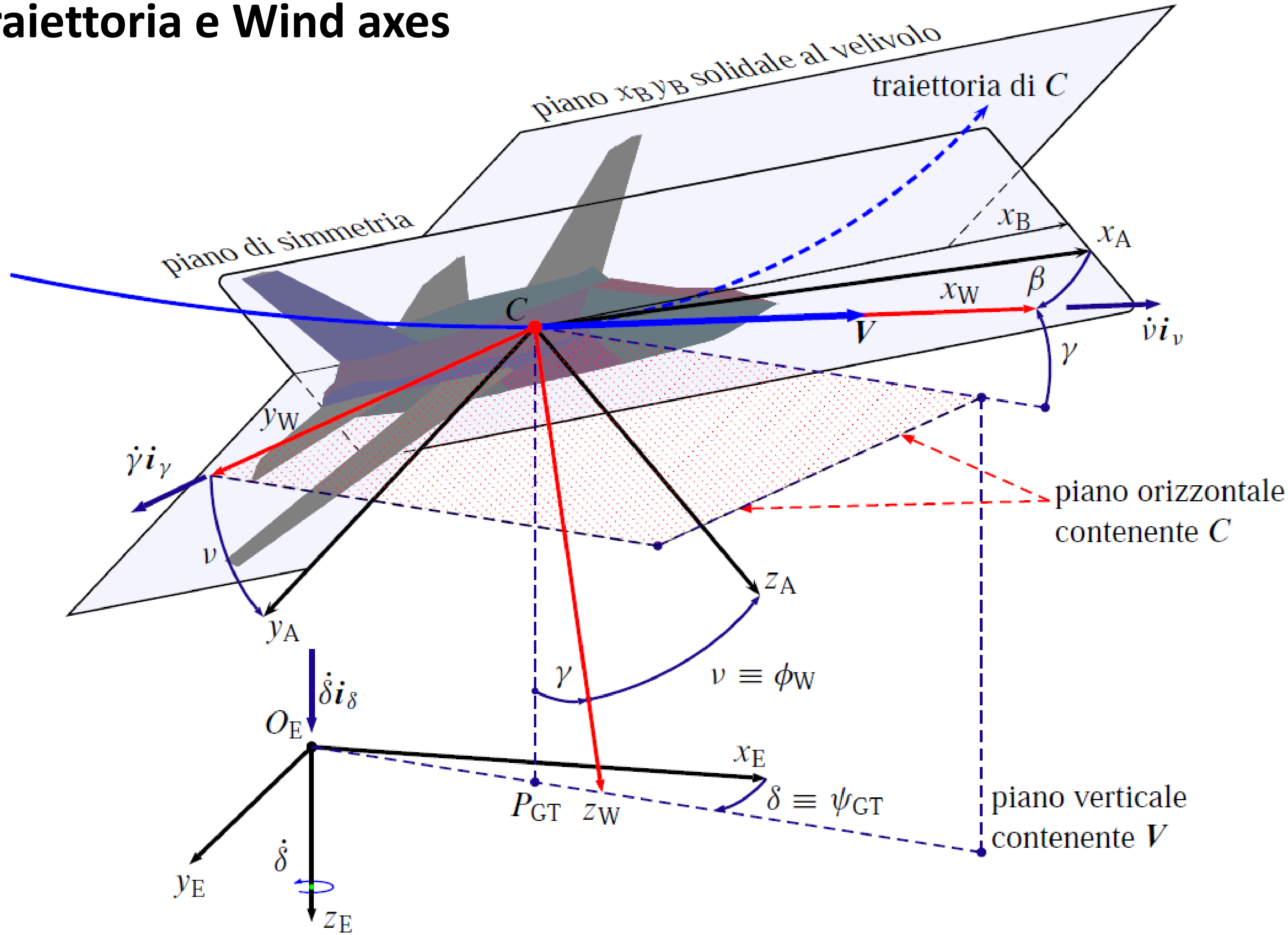


Figura 1.13 Assi vento (o assi traiettoria).

$$A = \dot{\nu}\, i_W + \dot{\alpha}\, j_B - \dot{\beta}\, k_A$$

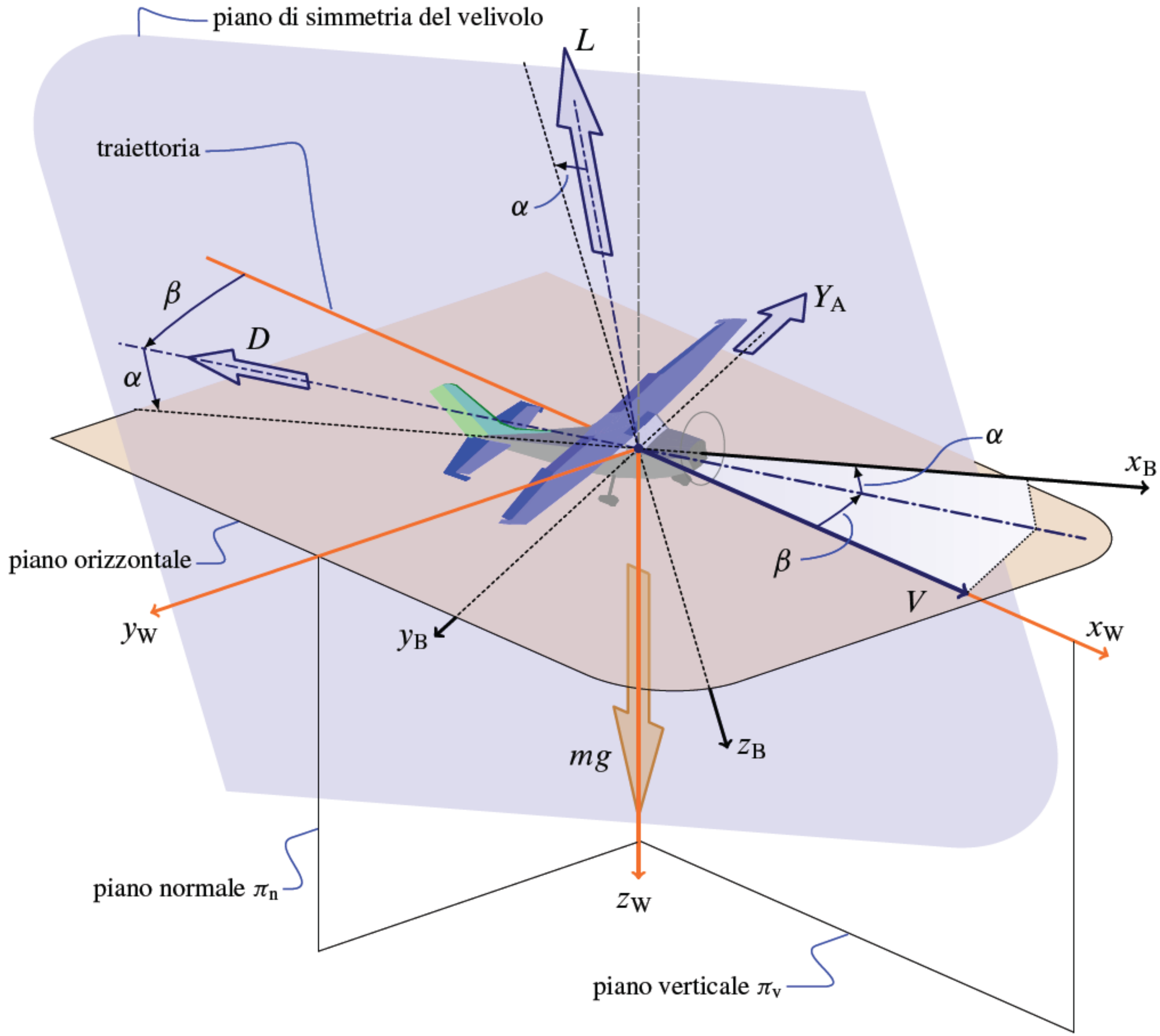


Figura 1.13 Terna di assi vento $\mathcal{T}_W = \{G, x_W, y_W, z_W\}$ (o assi traiettoria). In questa particolare circostanza la traiettoria del baricentro è orizzontale e l'orientamento del velivolo non è simmetrico rispetto al piano verticale $x_W z_W$.

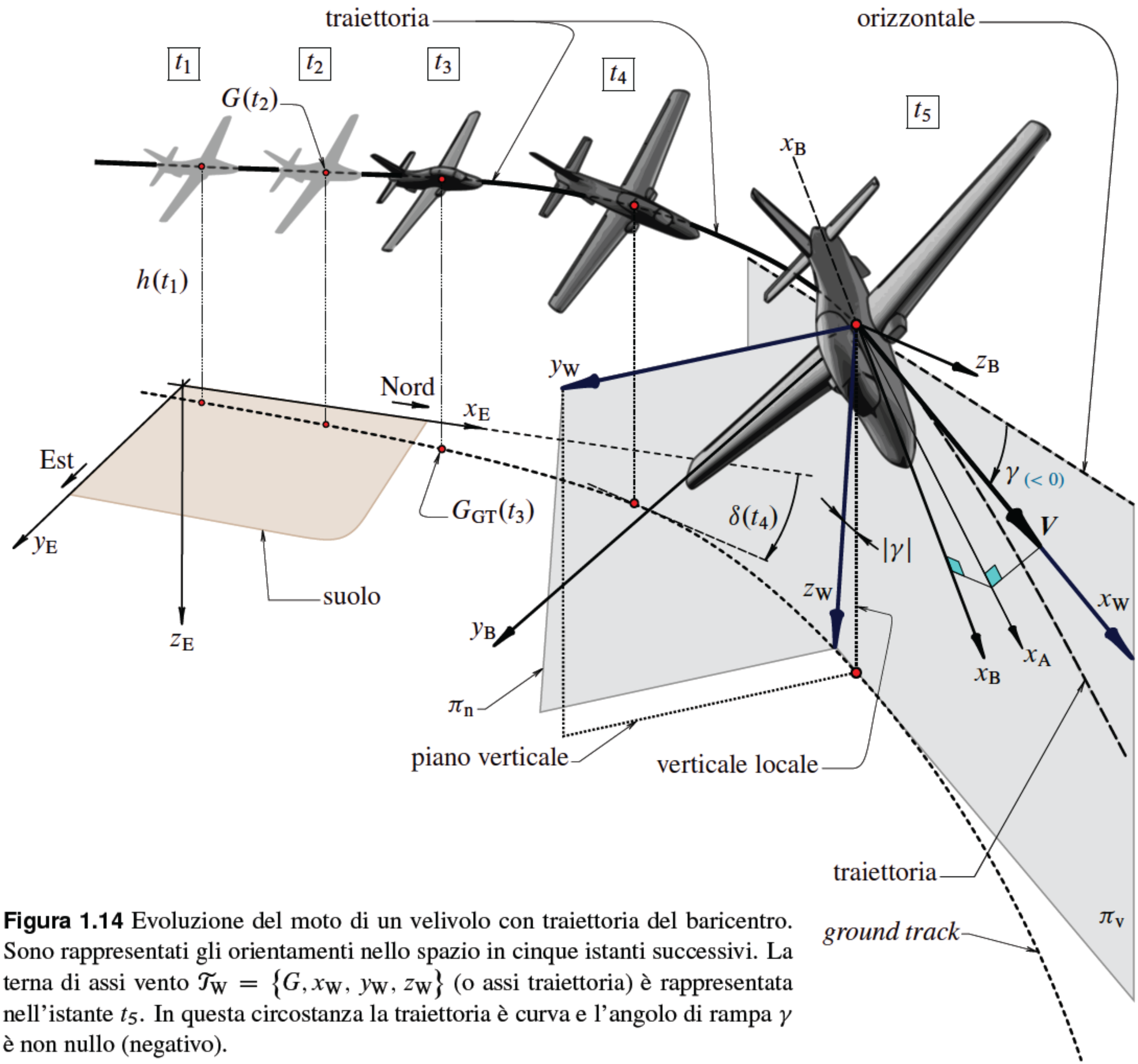


Figura 1.14 Evoluzione del moto di un velivolo con traiettoria del baricentro. Sono rappresentati gli orientamenti nello spazio in cinque istanti successivi. La terna di assi vento $\mathcal{T}_W = \{G, x_W, y_W, z_W\}$ (o assi traiettoria) è rappresentata nell'istante t_5. In questa circostanza la traiettoria è curva e l'angolo di rampa γ è non nullo (negativo).

Velocità angolare istantanea

Velocità angolare istantanea

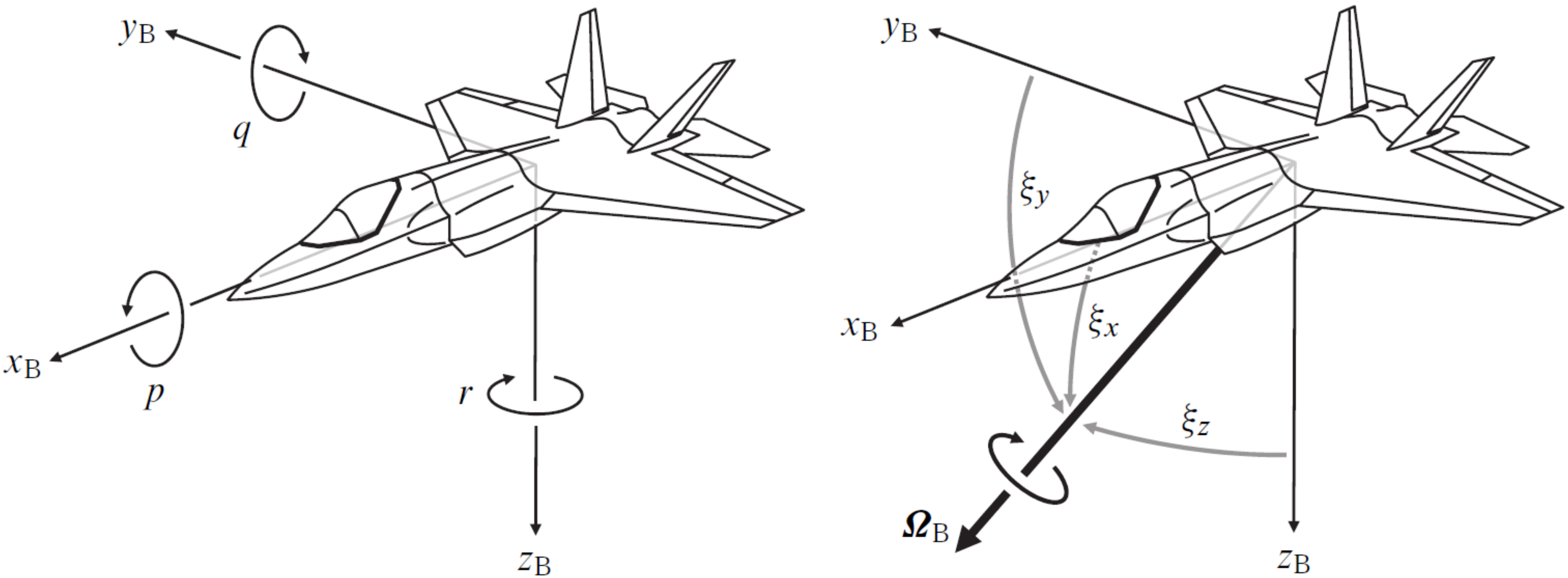


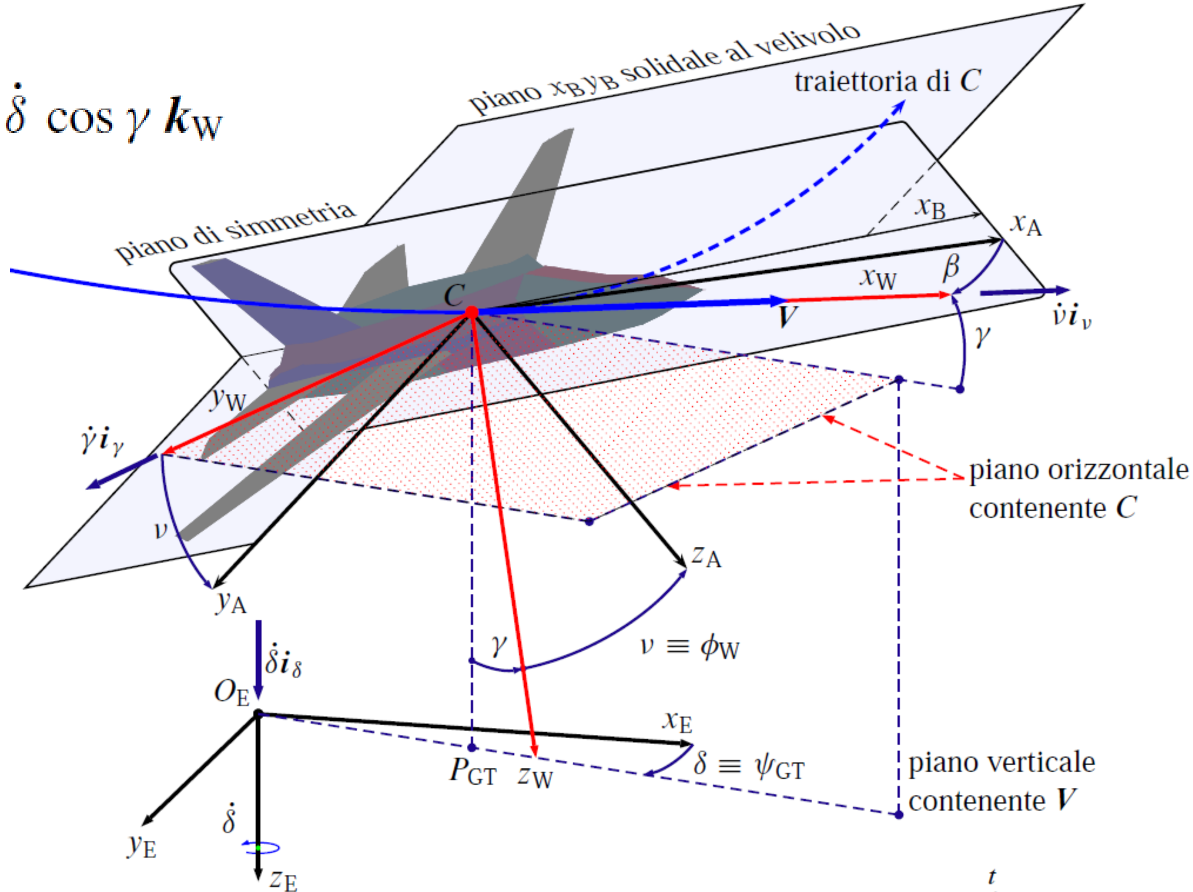
Figura 1.16 Vettore velocità angolare istantanea $\boldsymbol{\Omega}_B$ e sue componenti nel riferimento degli assi velivolo. La retta individuata dagli angoli ξ_x, ξ_y e ξ_z all'istante generico t rappresenta l'asse mobile intorno a cui il velivolo compie una rotazione rigida istantanea di entità $\Omega_B\,\mathrm{d}t$.

Evoluzione

$$\boldsymbol{E} = -\dot{\delta}\,\sin\gamma\,\boldsymbol{i}_{\mathrm{W}} + \dot{\gamma}\,\boldsymbol{j}_{\mathrm{W}} + \dot{\delta}\,\cos\gamma\,\boldsymbol{k}_{\mathrm{W}}$$

$$\boldsymbol{\Omega}_{\mathrm{W}} \equiv \boldsymbol{E}$$

$$E = \sqrt{\dot{\delta}^{\,2} + \dot{\gamma}^{\,2}}$$



$$x_{E,G}(t) = x_{E,G}(0) + \int_0^t V_{x_E}(\tau)\,d\tau$$

$$y_{E,G}(t) = y_{E,G}(0) + \int_0^t V_{y_E}(\tau)\,d\tau$$

$$z_{E,G}(t) = z_{E,G}(0) + \int_0^t V_{z_E}(\tau)\,d\tau$$

$$\delta(t) = \delta(0) + \int_0^t \dot{\delta}(\tau)\,d\tau \qquad \gamma(t) = \gamma(0) + \int_0^t \dot{\gamma}(\tau)\,d\tau$$

$$V_{x_E}(t) = V\,\cos\gamma\,\cos\delta\,, \quad V_{y_E}(t) = V\,\cos\gamma\,\sin\delta\,, \quad V_{z_E}(t) = -V\,\sin\gamma$$

Evoluzione

Assi aerodinamici

$$\boldsymbol{A} = \dot{\nu}\,\boldsymbol{i}_{\mathrm{W}} + \dot{\alpha}\,\boldsymbol{j}_{\mathrm{B}} - \dot{\beta}\,\boldsymbol{k}_{\mathrm{A}}$$

$$\boldsymbol{\Omega}_{\mathrm{A}} = \boldsymbol{E} + \dot{\nu}\,\boldsymbol{i}_{\mathrm{W}} - \dot{\beta}\,\boldsymbol{k}_{\mathrm{A}}$$

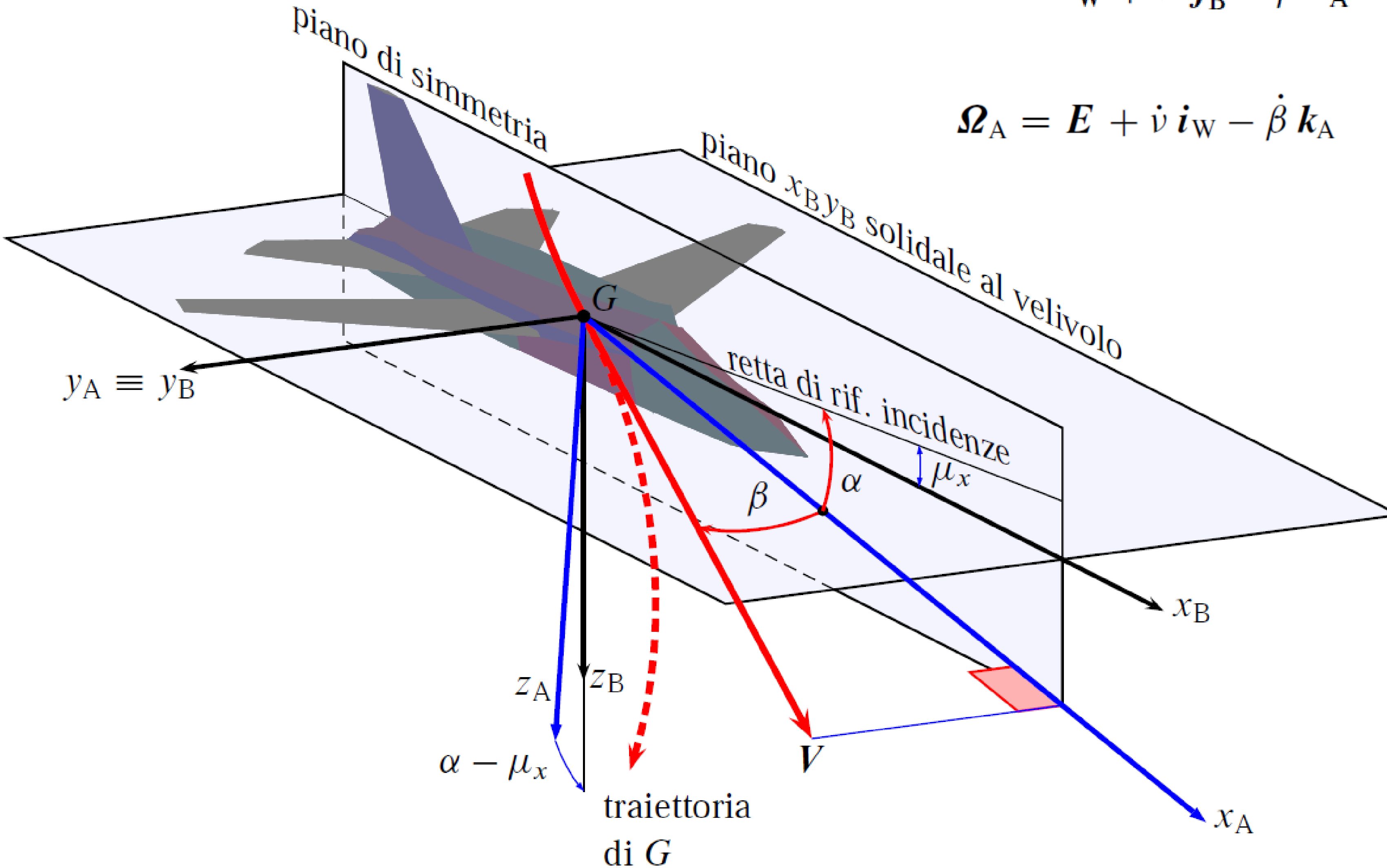


Figura 1.14 Assi aerodinamici ed assi velivolo.

Assi velivolo e angoli di Eulero

$$\boldsymbol{\Omega}_{\mathrm{B}} = \boldsymbol{\Omega}_{\mathrm{A}} + \dot{\alpha}\, \boldsymbol{j}_{\mathrm{B}}$$

$$\boldsymbol{A} = \dot{\nu}\, \boldsymbol{i}_{\mathrm{W}} + \dot{\alpha}\, \boldsymbol{j}_{\mathrm{B}} - \dot{\beta}\, \boldsymbol{k}_{\mathrm{A}}$$

$$\boldsymbol{\Omega}_{\mathrm{B}} = \boldsymbol{E} + \boldsymbol{A}$$

$$\boldsymbol{\Omega}_{\mathrm{B}} \cdot \boldsymbol{i}_{\mathrm{B}} = \Omega_{\mathrm{B},x_{\mathrm{B}}} \equiv p$$

$$\boldsymbol{\Omega}_{\mathrm{B}} \cdot \boldsymbol{j}_{\mathrm{B}} = \Omega_{\mathrm{B},y_{\mathrm{B}}} \equiv q$$

$$\boldsymbol{\Omega}_{\mathrm{B}} \cdot \boldsymbol{k}_{\mathrm{B}} = \Omega_{\mathrm{B},z_{\mathrm{B}}} \equiv r$$

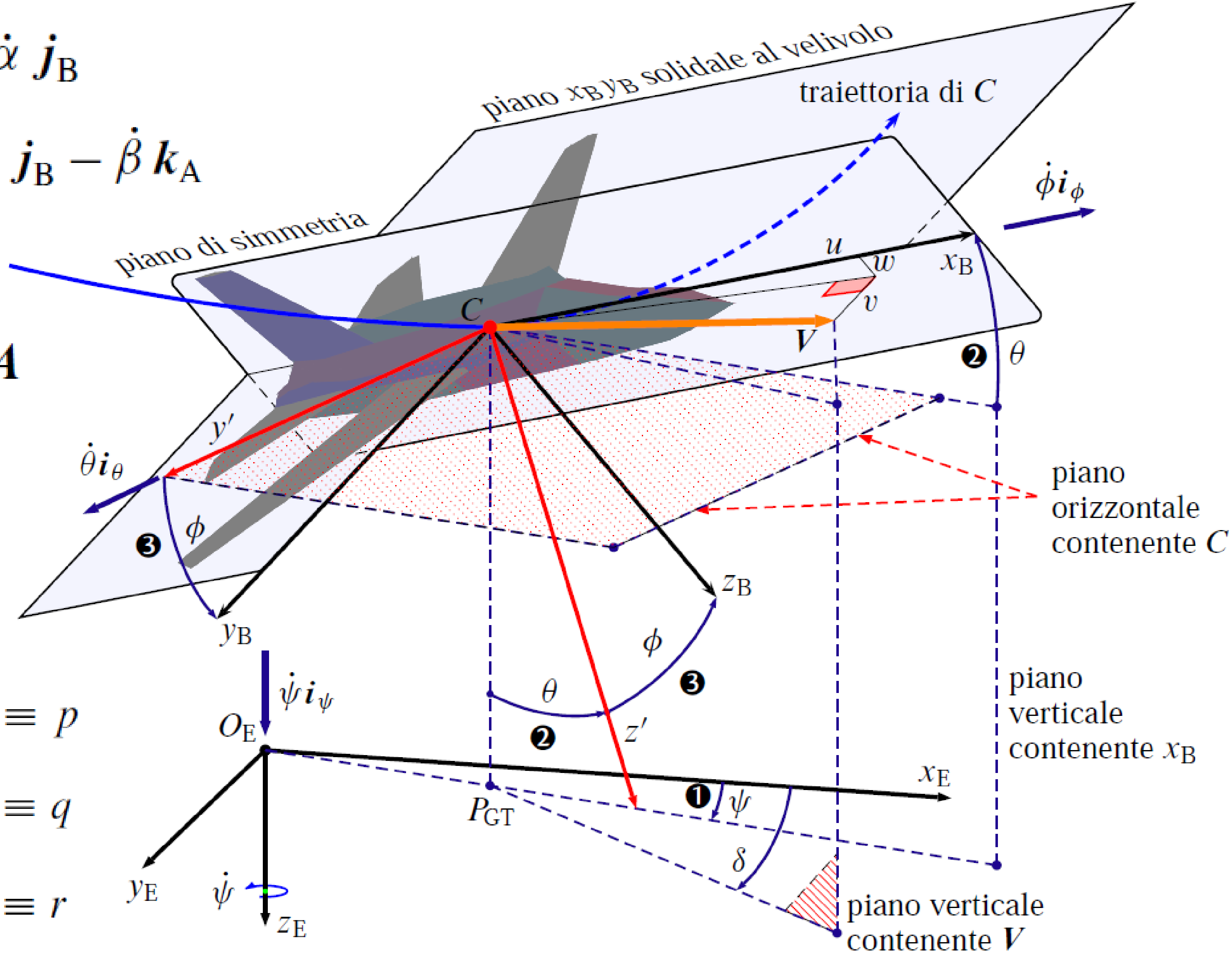


Figura 1.15 Assi velivolo ed angoli di Eulero.

(p, q, r)

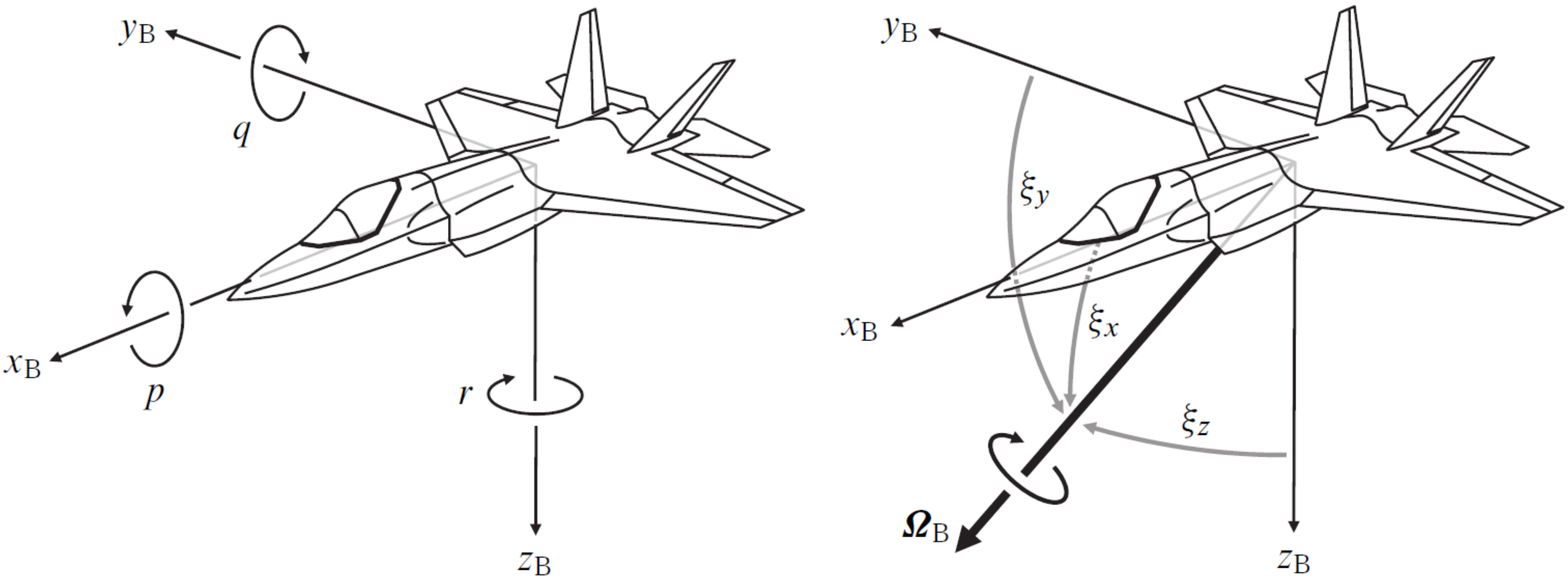


Figura 1.16 Vettore velocità angolare istantanea $\boldsymbol{\Omega}_B$ e sue componenti nel riferimento degli assi velivolo. La retta individuata dagli angoli ξ_x, ξ_y e ξ_z all'istante generico t rappresenta l'asse mobile intorno a cui il velivolo compie una rotazione rigida istantanea di entità $\Omega_B \, dt$.

$$p = \Omega_{A,x_B} \, , \qquad q = \Omega_{A,y_B} + \dot{\alpha} \, , \qquad r = \Omega_{A,z_B}$$

Moto vario

Angoli di Eulero

$$-\pi < \phi \le \pi$$
$$-\frac{\pi}{2} < \theta < \frac{\pi}{2}$$
$$0 \le \psi < 2\pi$$

$$\begin{aligned}\boldsymbol{\Omega}_\mathrm{B} &= \dot{\psi}\,\boldsymbol{i}_\psi + \dot{\theta}\,\boldsymbol{i}_\theta + \dot{\phi}\,\boldsymbol{i}_\phi \\ &= \left(\dot{\phi} - \dot{\psi}\,\sin\theta\right)\boldsymbol{i}_\mathrm{B} \\ &\quad + \left(\dot{\psi}\,\cos\theta\,\sin\phi + \dot{\theta}\,\cos\phi\right)\boldsymbol{j}_\mathrm{B} \\ &\quad + \left(\dot{\psi}\,\cos\theta\,\cos\phi - \dot{\theta}\,\sin\phi\right)\boldsymbol{k}_\mathrm{B}\end{aligned}$$

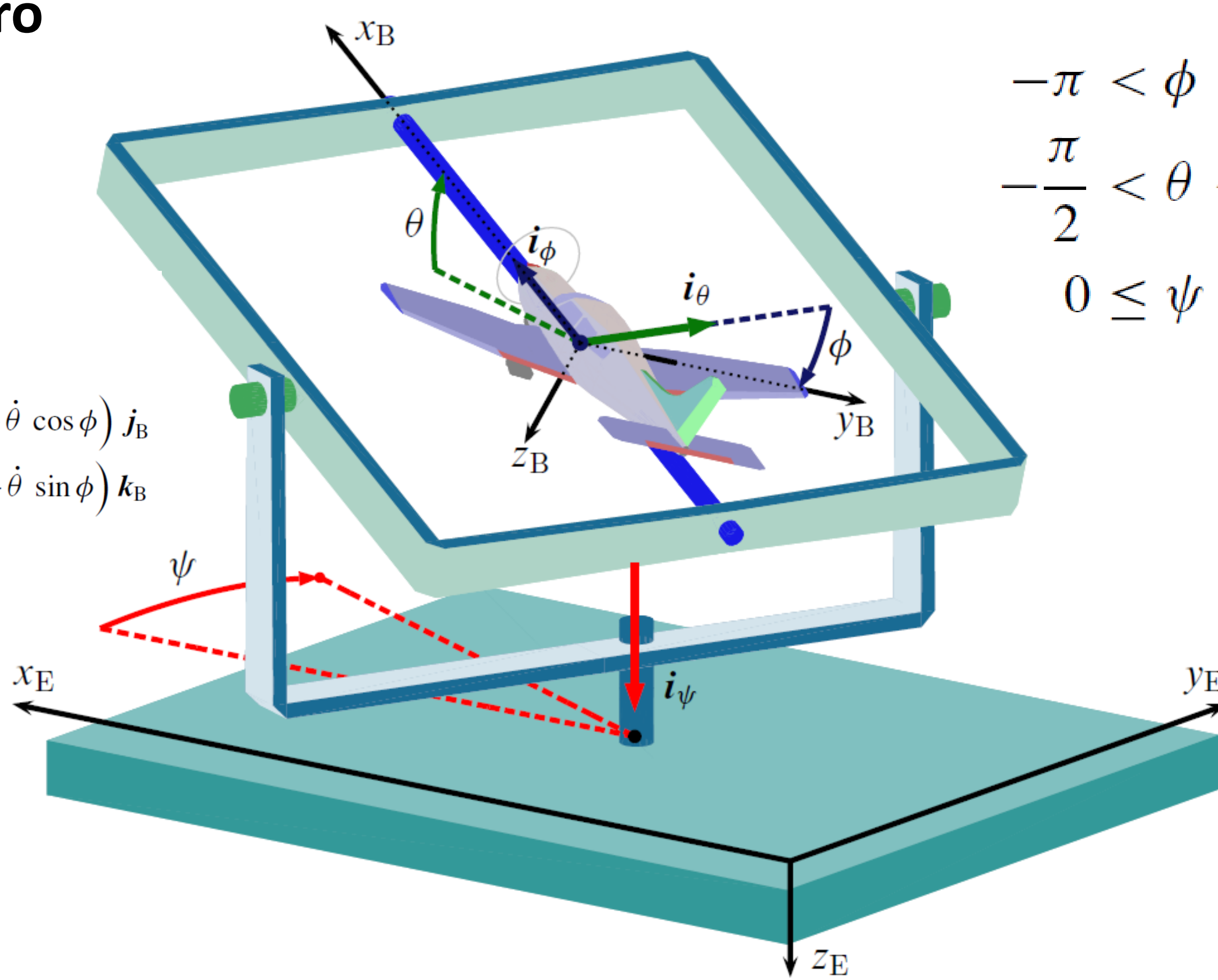


Figura 1.17 Angoli di Eulero dell'orientamento di un velivolo. Interpretazione che utilizza lo snodo cardanico (*gimbal*).

Angoli di Eulero

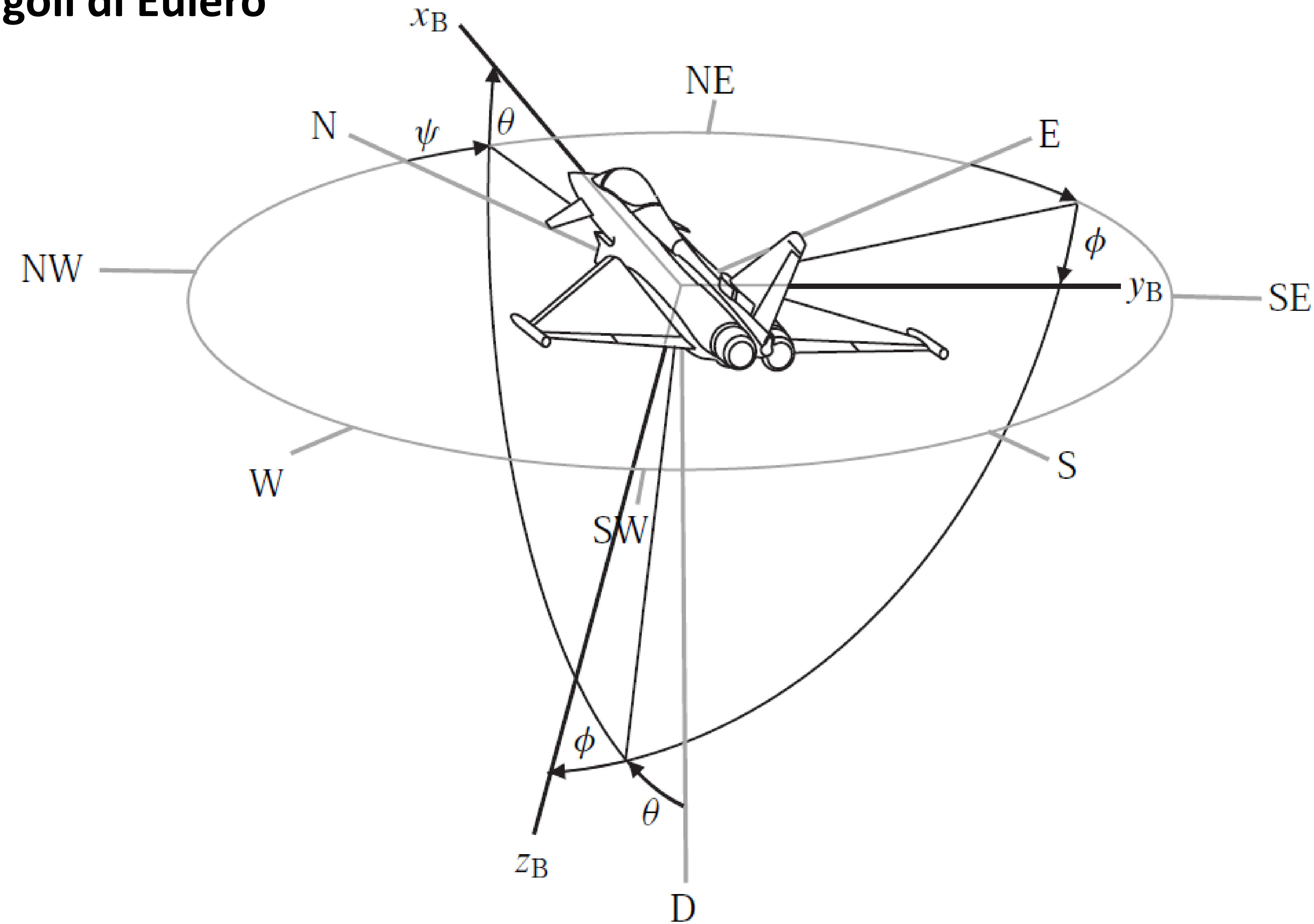


Figura 1.18 Orientamento del velivolo e significato degli angoli di Eulero rispetto alla usuale simbologia degli indicatori di bordo (*Horizontal Situation Indicator*, HSI).

Traiettoria e ground track

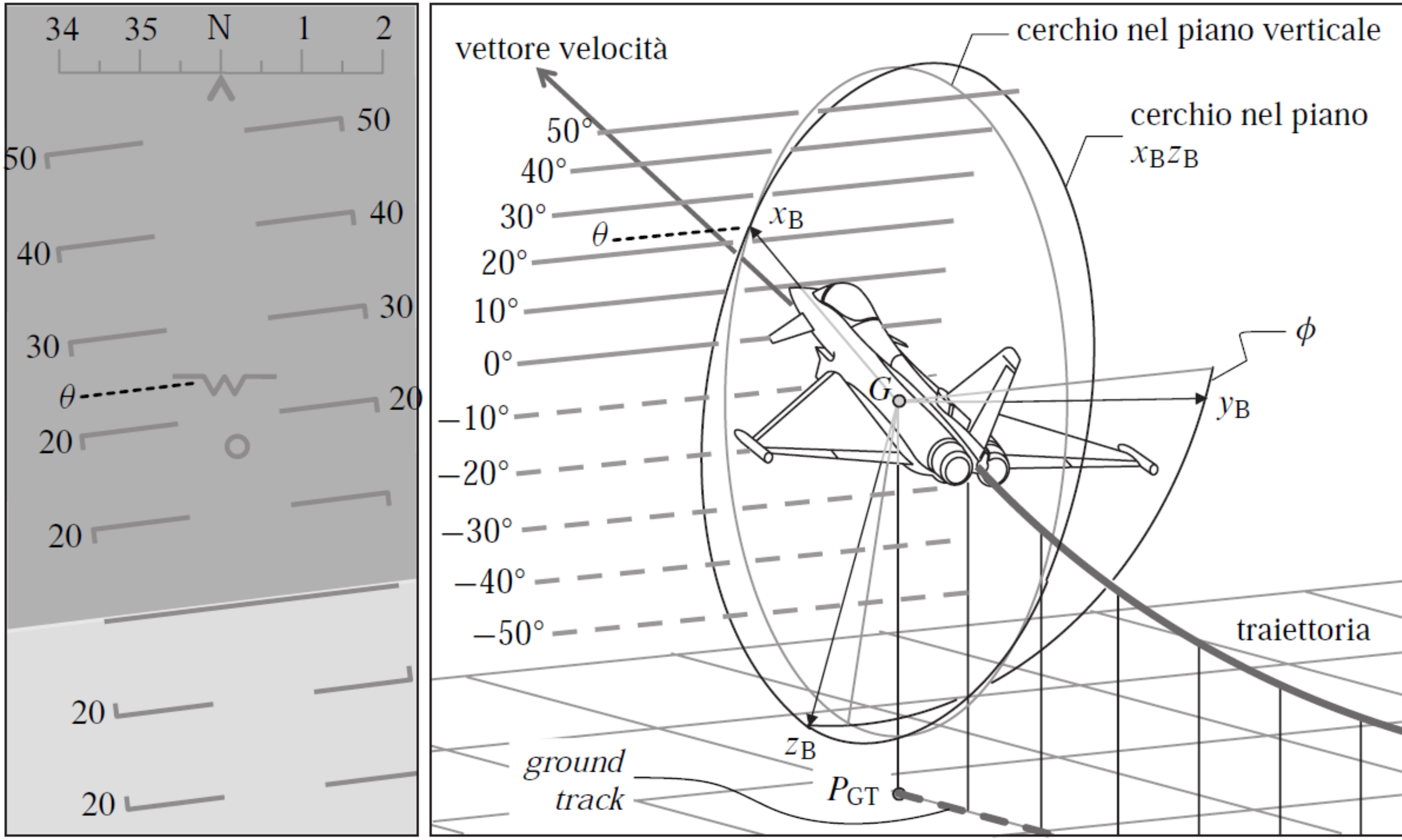


Figura 1.19 Traiettoria e *ground track*. Interpretazione dell'angolo di elevazione θ e di inclinazione laterale ϕ attraverso gli indicatori tipici di un *Head-Up-Display*.

Assi costruttivi

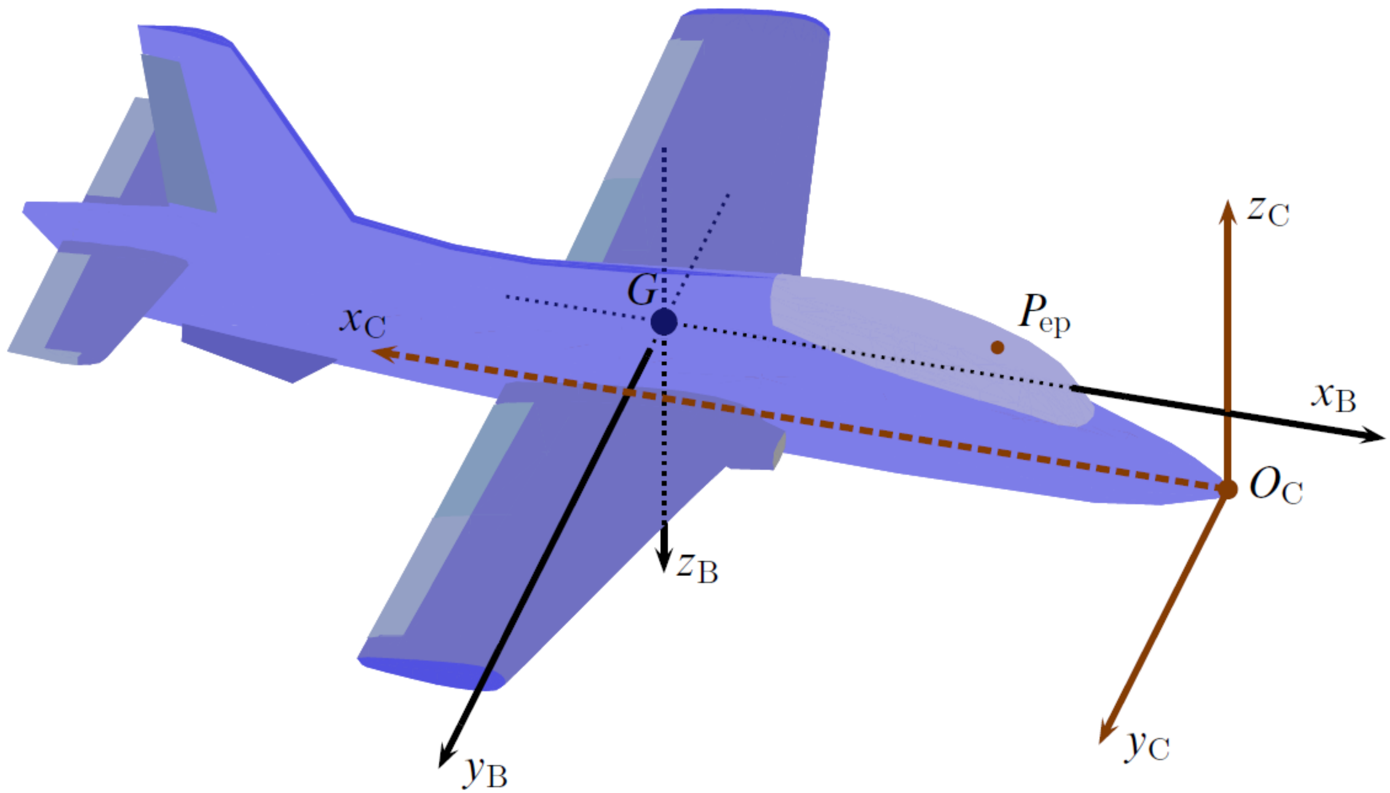


Figura 1.20 Assi velivolo ed assi costruttivi. Il punto P_{ep} è detto *pilot eye-point* ed indica la posizione della testa del pilota nel riferimento costruttivo.

Assi costruttivi

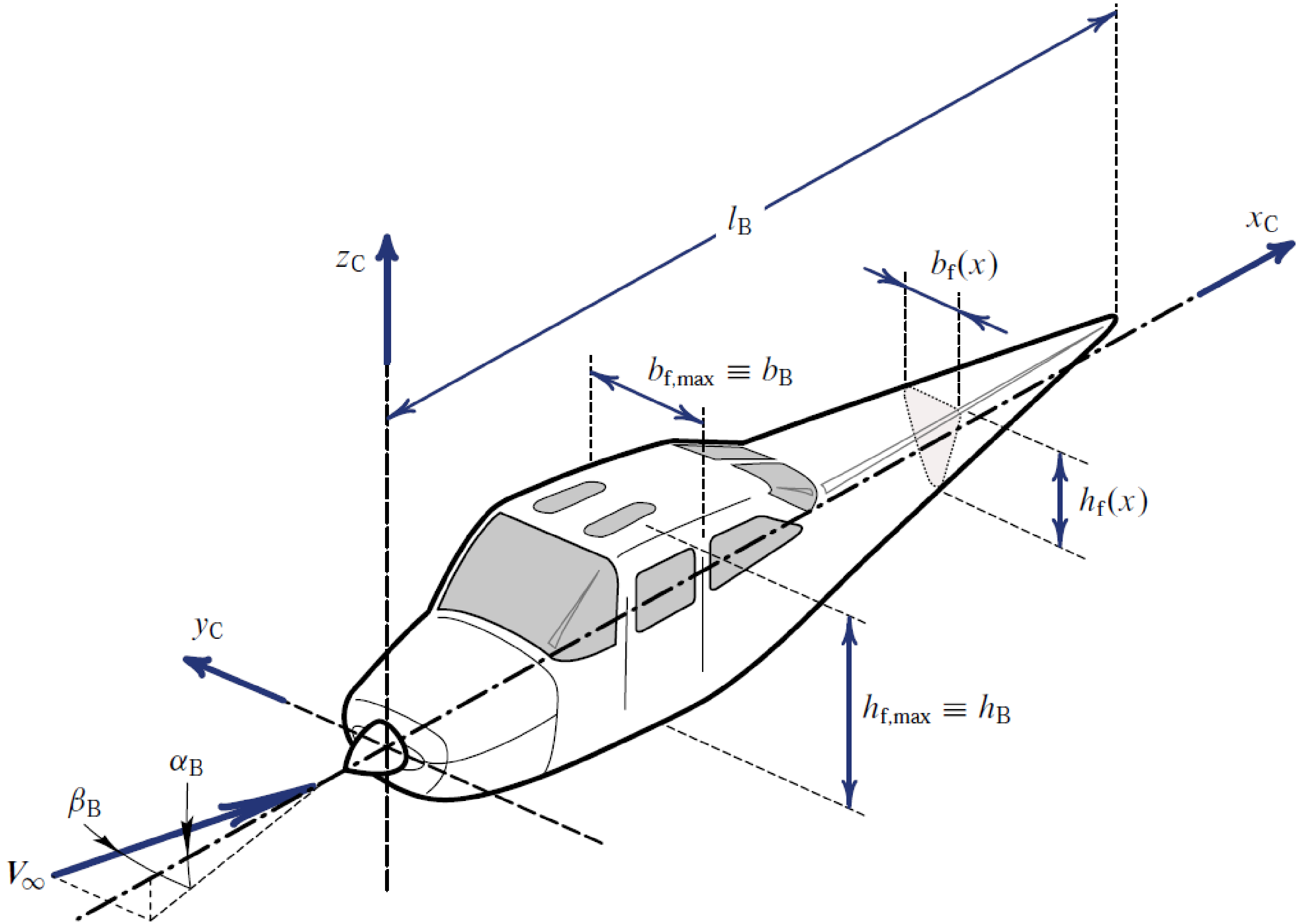


Figura 1.21 Parametri geometrici di una fusoliera.

Assi costruttivi

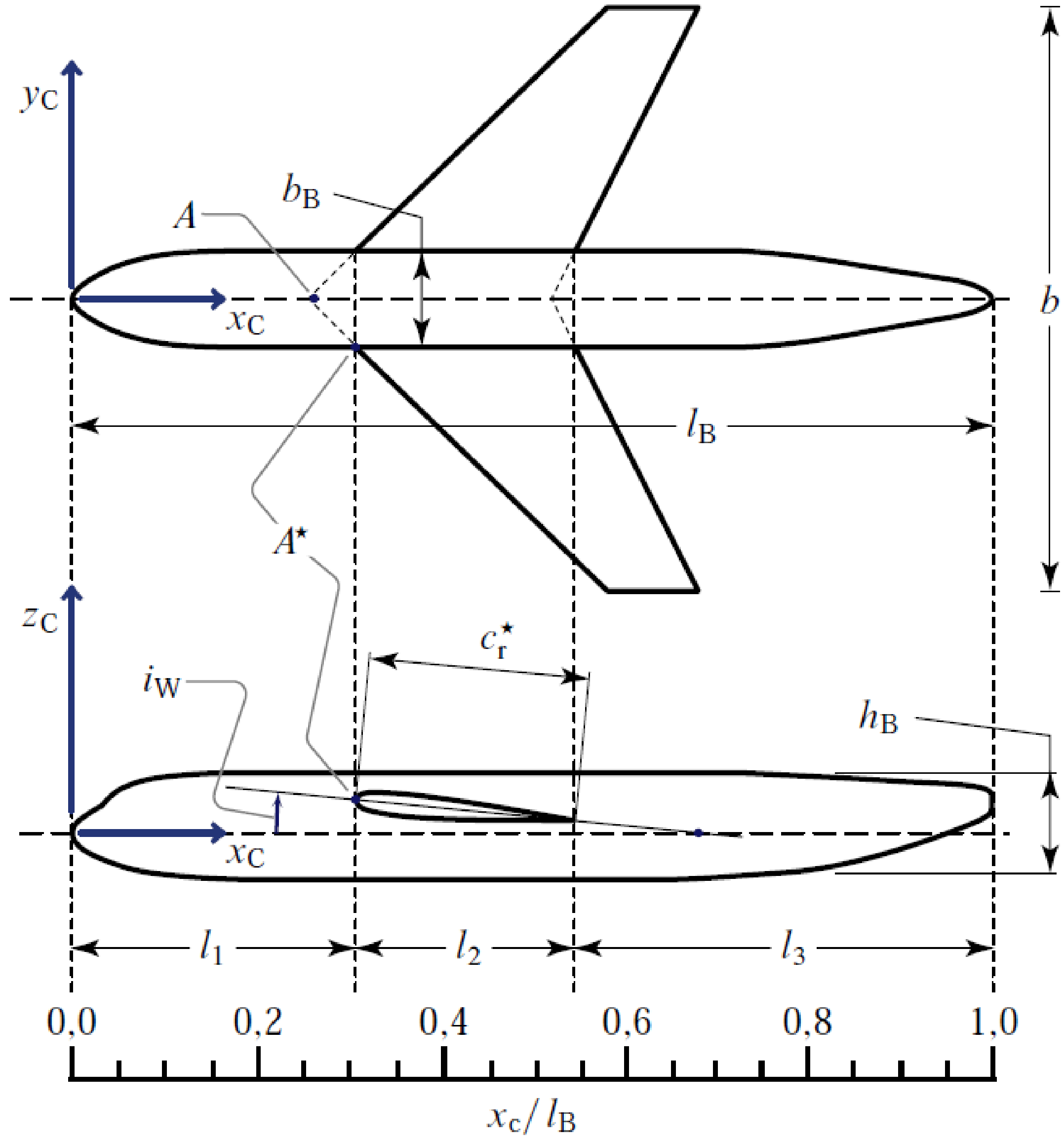


Figura 1.22 Definizioni relative alla configurazione ala-fusoliera (vista dall'alto e vista laterale).

Assi costruttivi

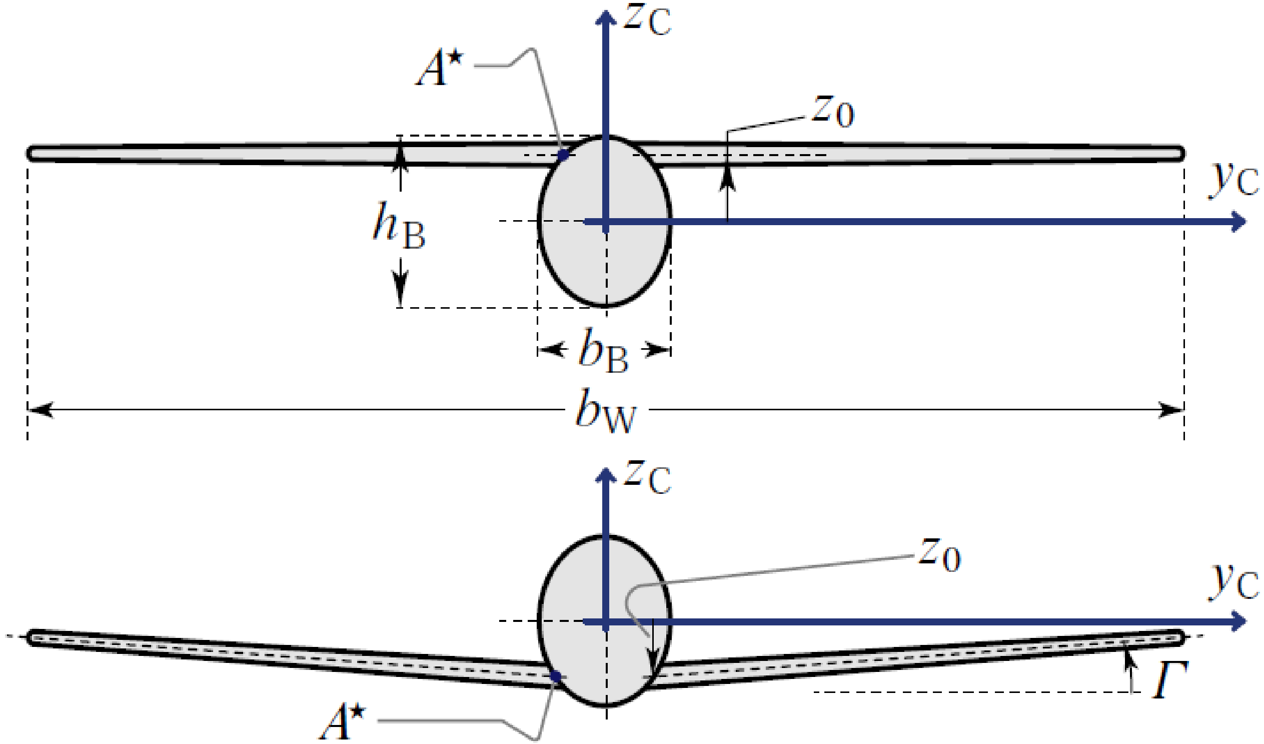


Figura 1.23 Definizioni relative alla configurazione ala-fusoliera (vista frontale).

Comandi di volo

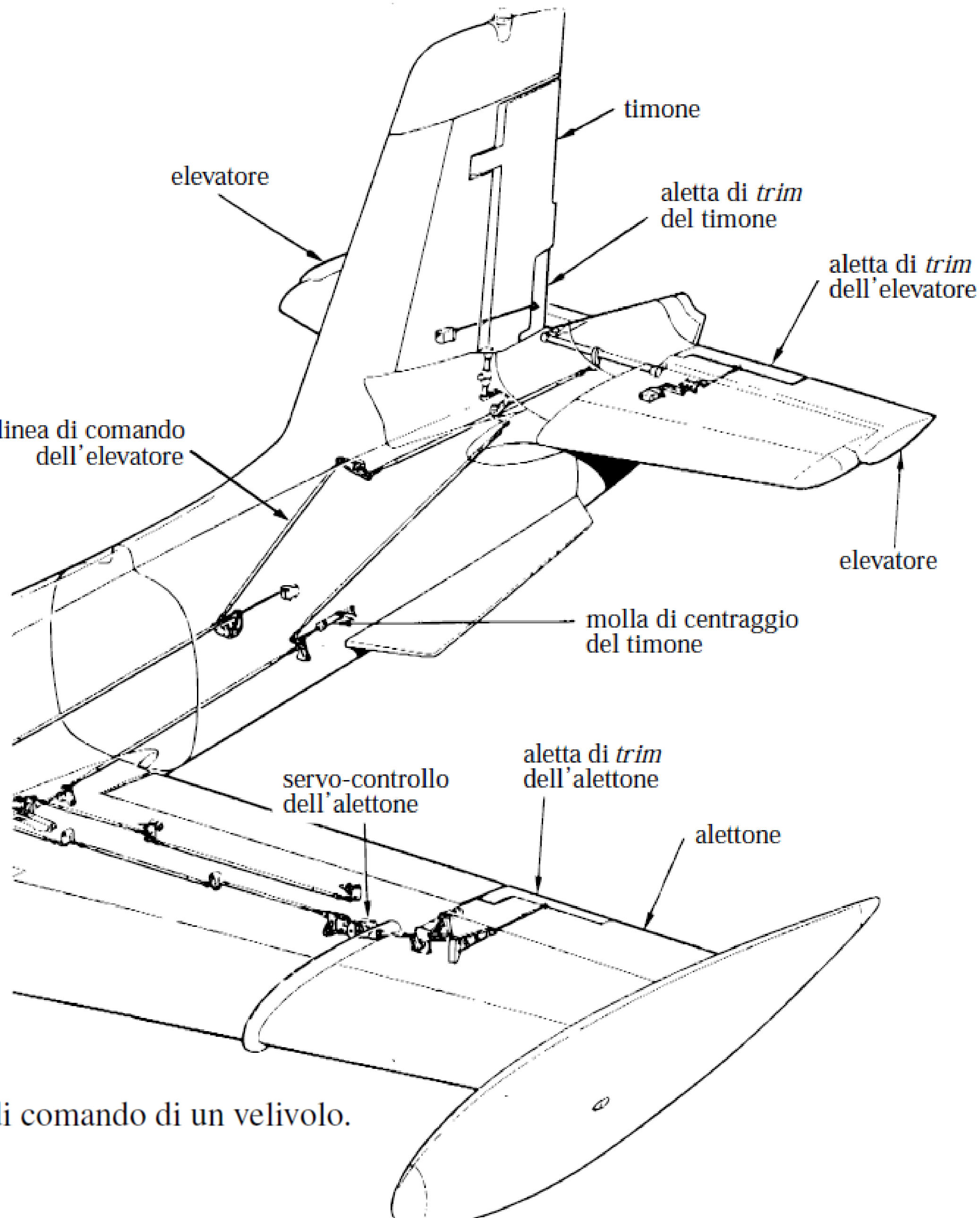


Figura 1.27 Linee di comando di un velivolo.

Assi superficie di comando

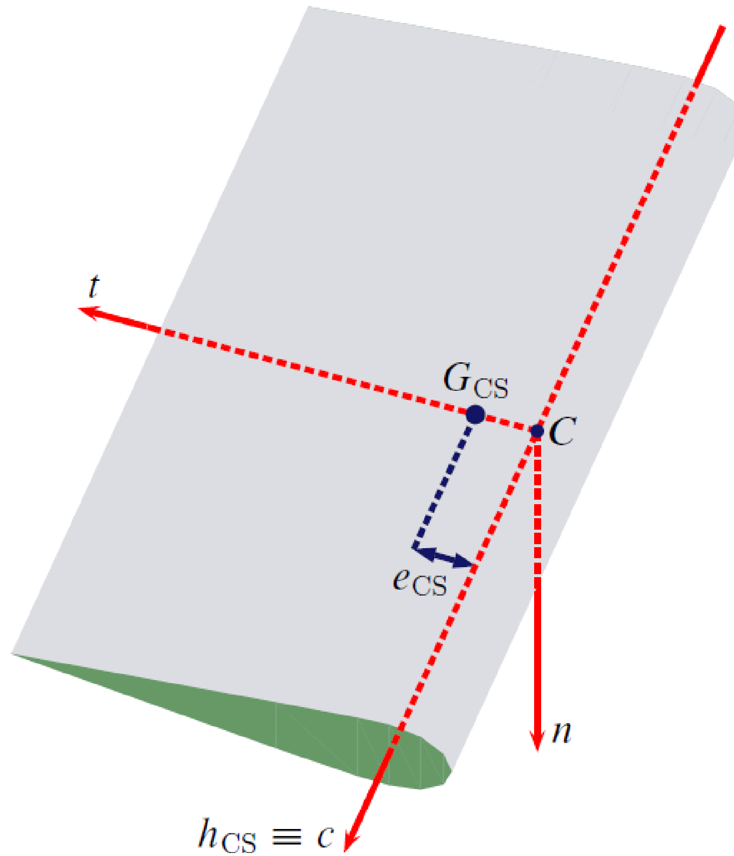


Figura 1.28 Generica terna $\mathcal{T}_{\mathrm{CS}} = \{C, c, t, n\}$ degli assi superficie di governo. Essa si specializza, ad esempio nel caso dell'equilibratore, nella terna $\mathcal{T}_{\mathrm{CS,e}} = \{C_{\mathrm{e}}, h_{\mathrm{e}}, t_{\mathrm{e}}, n_{\mathrm{e}}\}$ e l'eccentricità diviene $e_{\mathrm{CS}} \equiv e_{\mathrm{e}}$.

Assi superficie di comando

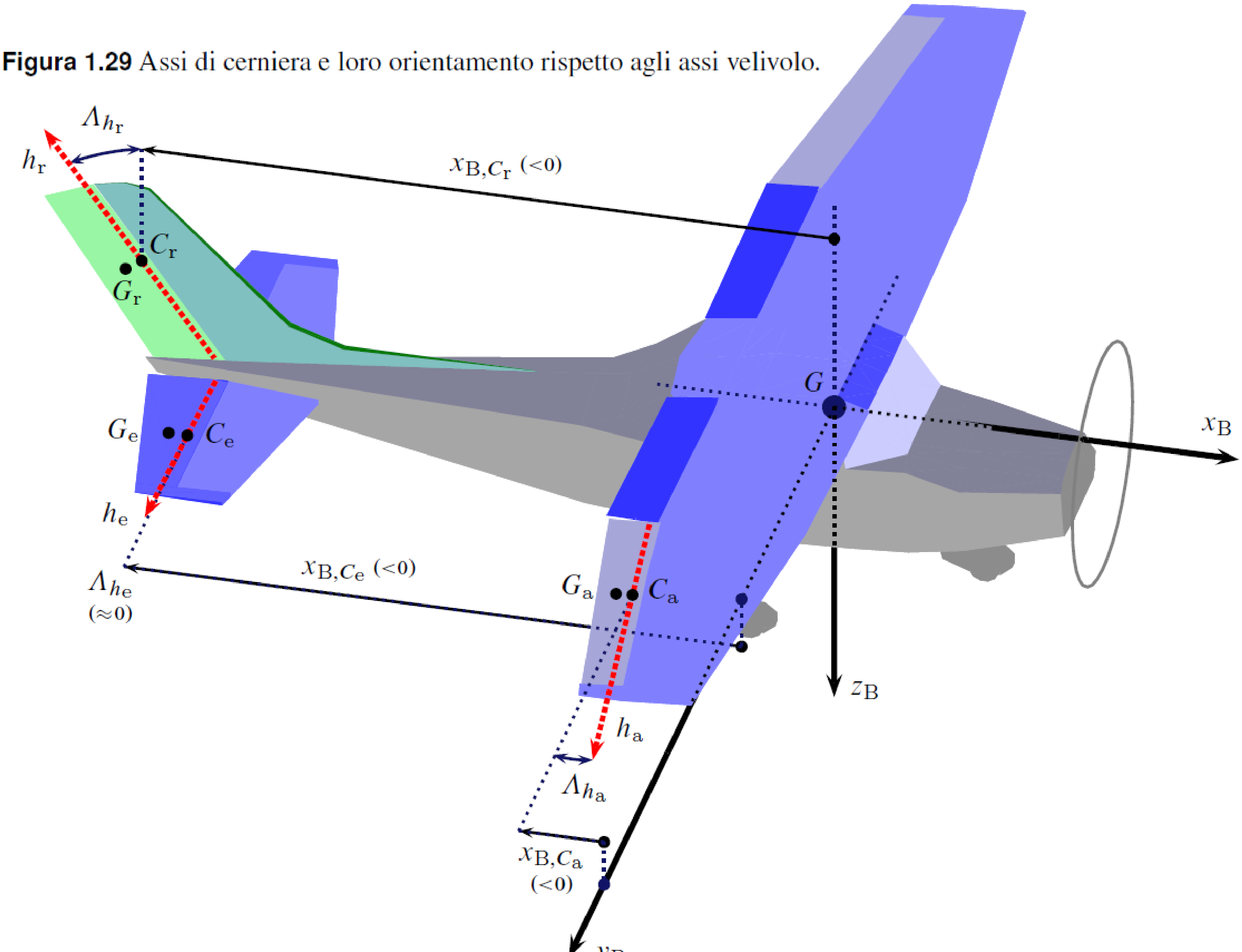


Figura 1.29 Assi di cerniera e loro orientamento rispetto agli assi velivolo.