

Dinamica e simulazione di volo

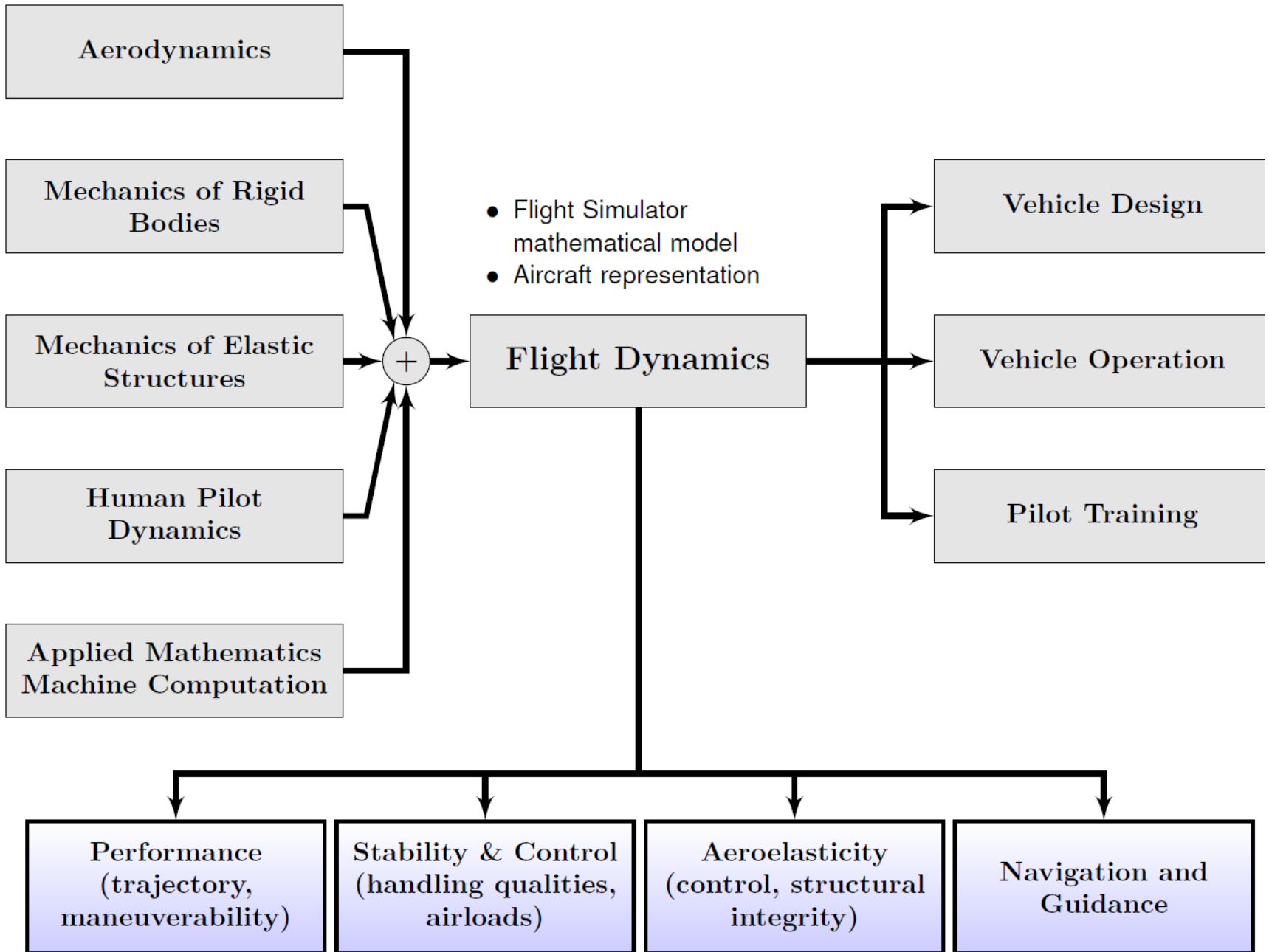
Laurea Magistrale, I anno, 6CFU

prof. Domenico Coiro

prof. Agostino De Marco: agostino.demarco@unina.it

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

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



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.
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- 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.
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- Perkins, C., and Hage, R., *Airplane Performance Stability and Control*, J. Wiley & Sons, 1949.
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- 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>

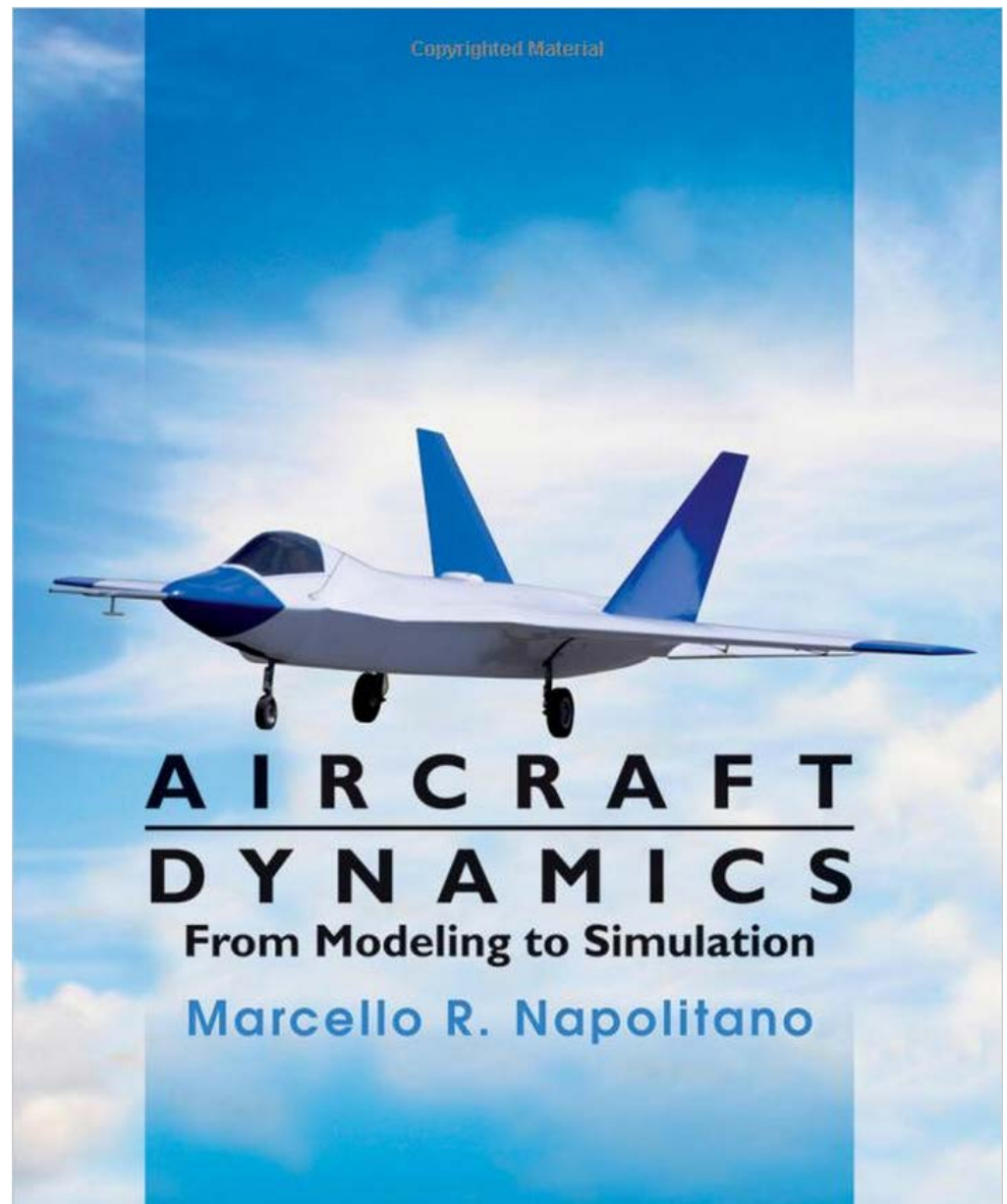
Riferimenti

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

The screenshot shows the MIT OpenCourseWare website interface. At the top, the MIT logo and 'MITOPENCOURSEWARE MASSACHUSETTS INSTITUTE OF TECHNOLOGY' are visible. A navigation bar includes 'Home', 'Courses', 'Donate', 'About OCW', 'Help', and 'Contact Us'. A search bar is present with the text 'Enter search keyword' and a 'GO' button. On the right, there is a 'SIGN UP FOR OCW NEWS' button. The main content area displays the course title '16.333 Aircraft Stability and Control' and 'As taught in: Fall 2004'. A large image of a B-1 Lancer bomber is shown. To the right of the image, the course level is 'Graduate' and the instructor is 'Prof. Jonathan P. How'. Below this, there are links for 'Course Features', 'Course Description', and 'Technical Requirements'. A sidebar on the left contains a list of course-related links such as 'VIEW ALL COURSES', 'Course Home', 'Syllabus', 'Calendar', 'Lecture Notes', 'Assignments', 'Download Course Materials', and 'Send us your feedback'. At the bottom of the sidebar is a 'SHARE' button with social media icons. On the right side of the main content, there is a 'DONATE NOW' button and a testimonial box titled 'WHY I DONATE' featuring a quote from Ray Fix, Self Learner USA, and a 'Read more' link. Below the testimonial is an 'MIT NOTICE' section with a 'next >' link and a question: 'Are nanoparticles harmful to the environment?'. At the bottom right of the notice is a link 'Ask an Engineer at MIT >'. The course description at the bottom of the page begins with 'This class includes a brief review of applied aerodynamics and modern approaches in'.

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

Home Courses Donate About OCW Help Contact Us Enter search keyword GO > Advanced Search

Home > Courses > Aeronautics and Astronautics > Feedback Control Systems

16.31 Feedback Control Systems

As taught in: Fall 2007



Level:
Graduate

Instructors:
Prof. Jonathan P. How

Course Features
Course Description

Highly maneuverable aircraft, like this X-29, often require sophisticated control systems to fly stably. (Photo courtesy of NASA Dryden Flight Research Center Photo Collection.)

Course Features

- > Lecture notes
- > Assignments (no solutions)

Course Description

This course covers the fundamentals of control design and analysis using state-space methods. This includes both the practical and theoretical aspects of the topic. By the end of the course, the student should be able to design controllers using state-space methods and evaluate whether these controllers are robust.

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<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/>

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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	Download
Binary for Linux 64 bit	stable	Built with Intel Fortran compiler. Run <code>sudo cp datcom /usr/bin/</code> to be able to run the <code>[datcom]</code> command from the terminal.	2010-01-16	Download ..
Binary for Linux 32 bit	stable	Simply run <code>sudo cp -a datcom /usr/bin/</code> at the terminal to paste the binary into your user bin file allowing you to type <code>datcom</code> at the terminal. This was compiled with intel FORTRAN compiler.	2010-01-04	Download ..
Binary for Windows	stable	Unzip the folder, run <code>datcom.bat</code> from the command prompt to set the binary path. Enter the folder through the command prompt and type <code>datcom</code> 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)

www.flightgear.org


FlightGear
sophisticated, professional, open-source flight simulation

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http://www.flightgear.org

FlightGear Flight Simulator: Version 2.6

- sophisticated, professional, open-source.
- Feb 17, 2012:** Read the [FlightGear v2.6 released announcement!](#)

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- Advanced Weather v1.4 in Flightgear 2.6+
- FlightGear v2.6.0 Released
- Sky Diving Visualization
- Interview: Durk Talsma

Recent Comments

- FlightGear 2.6.0 Released | gamesflightsimulators.com on FlightGear v2.6.0 Released
- FlightGear Version 2.6.0 Updates | Aerosoft Sim News on Web Site Updates
- lucas on Advanced Weather v1.4 in Flightgear 2.6+
- Catalanoic on Advanced Weather v1.4 in Flightgear 2.6+
- Catalanoic on FlightGear v2.6.0 Released

Download the FlightGear Program, Aircraft, Scenery, Source Code, Release Candidates, Development Snaphots ...

- Find what you are looking for at the [Master Download Portal](#) page.

<http://www.flightgear.org>

Ritrovaci su Facebook



Ti piace. Non mi piace più

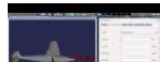
JSBSim Open Source Flight
Dynamics Software Library

NASA To Host Open Source
Summit March 29-30 In
California | SpaceRef - Your
Space Reference
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NASA To Host Open Source
Summit March 29-30 In
California - SpaceRef

eri alle ore 5.32

JSBSim Open Source Flight
Dynamics Software Library More
cool! work by James Goppert using
JSBSim.



A 89 persone piace JSBSim Open
Source Flight Dynamics Software

JSBSim is an open source flight dynamics model (FDM) that compiles and runs under many operating systems, including Microsoft Windows, Apple Macintosh, Linux, IRIX, Cygwin (Unix on Windows), etc. The FDM is essentially the physics/math model that defines the movement of an aircraft, rocket, etc., under the forces and moments applied to it using the various control mechanisms and from the forces of nature. JSBSim has no native graphics. It can be run by itself as a standalone program, taking input from a script file and various vehicle configuration files. It can also be incorporated into a larger flight simulator implementation that includes a visual system. The most notable examples of the use of JSBSim are currently seen in the **FlightGear** (open source), **Outerra**, **BoozSimulator** (open source), and **OpenEagles** (open source) simulators. JSBSim is also used to drive the motion-base research simulators at the **University of Naples, Italy**, and in the **Institute of Flight System Dynamics** and **Institute of Aeronautics and Astronautics** at RWTH Aachen University in Germany.

Features include:

- Fully configurable flight control system, aerodynamics, propulsion, landing gear arrangement, etc. through XML-based text file format.
- Rotational earth effects on the equations of motion (coriolis and centrifugal acceleration modeled).
- Configurable data output formats to screen, file, socket, or any combination of those.

See our **flyer** for additional information.

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<http://www.jsbsim.org>



ScicosLab

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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.

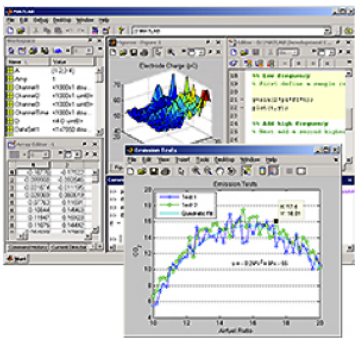
ScicosLab is the new name of ScilabGtk. This change of name has been decided in order to avoid all confusion with Scilab, which is no longer developed at INRIA. ScicosLab is developed by some of the researchers who originally developed Scilab at INRIA and ENPC. ScicosLab is used in particular for distributing 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 Overview

- Description
- Function List
- Demos and Webinars
- System Requirements
- Latest Features
- Support & Training
 - Product Support
 - Documentation
 - Downloads & Trials
 - Training
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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 - 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
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- Downloads
- 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.

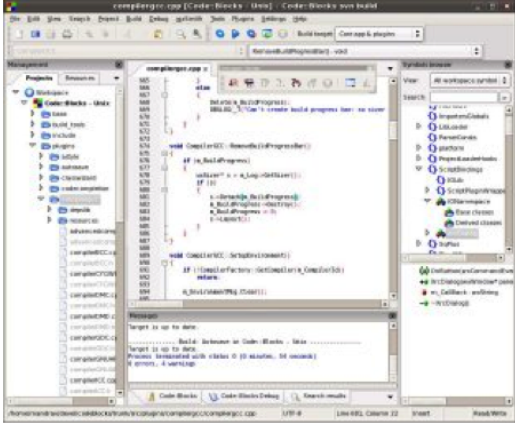
Code::Blocks is a *free C++ IDE* built to meet the most demanding needs of its users. It is designed to be very extensible and fully configurable.

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 [download page](#)



Visual C++ 2010 Express

Microsoft®/Express

English

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Visual Studio 2010 Express

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Although Microsoft Visual Studio 2010 Express products are provided free of charge, we do require that you register your product within **30 days of installation** for continued use. If you are not sure how to obtain your **free** Visual Studio 2010 Express registration key, follow these [instructions](#).

- ▶ Visual Basic 2010 Express
- ▶ Visual C# 2010 Express
- ▶ Visual C++ 2010 Express

Install Visual C++ 2010 Express

Select language...

- ▶ Visual Web Developer 2010 Express
- ▶ All - Offline Install ISO image file



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Aerobatics and spins in Flightgear Sim DR400 ROBIN.wmv

Flightgearsim



Iscriviti

73 video ▾



Mi piace



+ Aggiungi a ▾

Condividi



254 visualizzazioni



Caricato da [Flightgearsim](#) in data 05/nov/2010

FlightGear flight simulator spin testing Dany's modified DR400-jsbSim Robin aeroplane was great fun and it does nice aerobatics too!

2 Mi piace, 0 Non mi piace

<http://youtu.be/Mj9CZfYa3cl>

Concetti introduttivi



Anatomia del velivolo

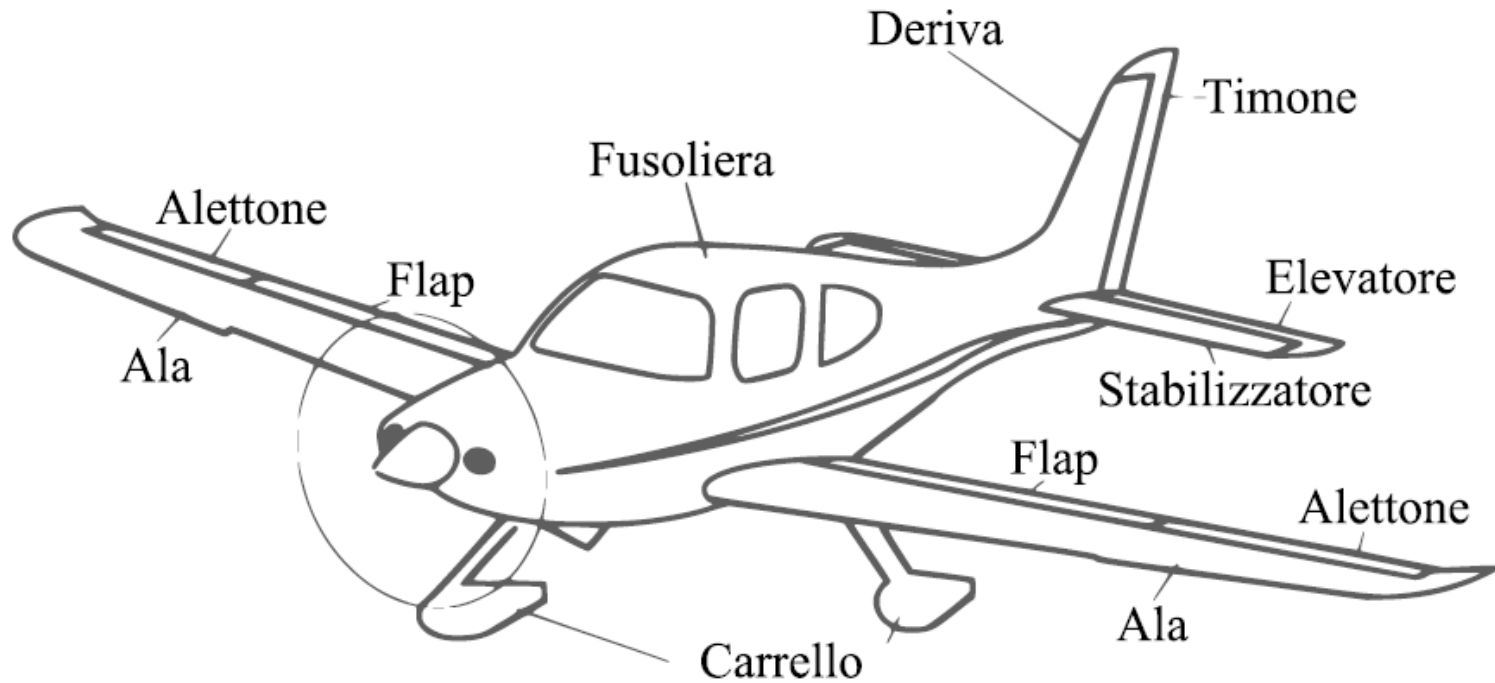


Figura 1.1 Anatomia di un velivolo di architettura tradizionale.

Anatomia del velivolo

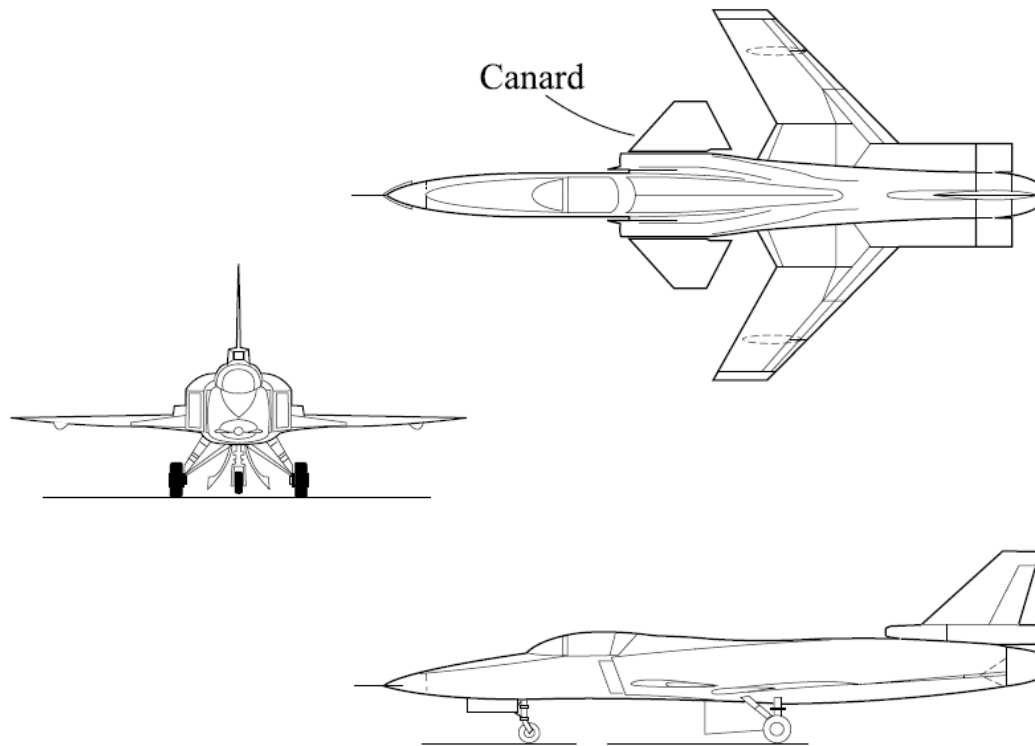


Figura 1.2 Un esempio di velivolo ad architettura non tradizionale, dotato di alette *canard* e di ali a freccia negativa, l'americano Grumman X29.

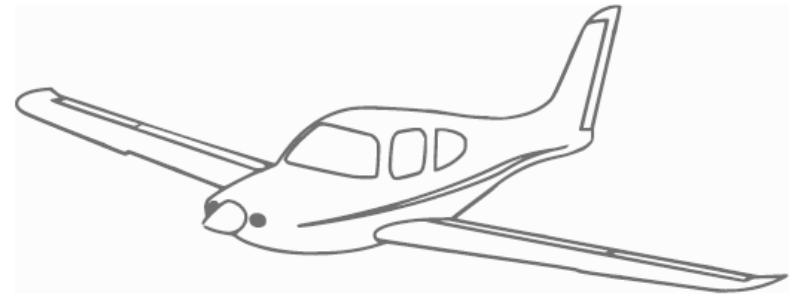
Anatomia del velivolo



Scomposizione della configurazione aerodinamica



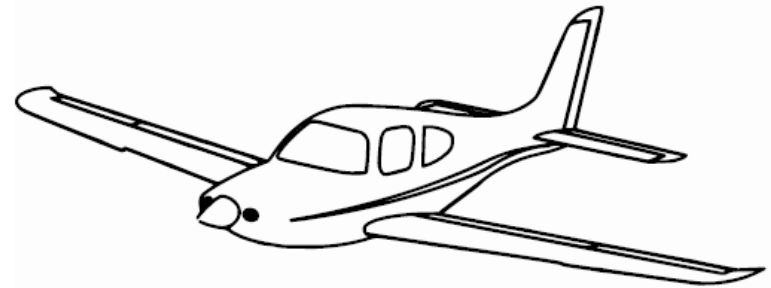
(a) *wing-body (WB)*



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



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



(d) *Velivolo completo*

Figura 1.3 Possibili sottoinsiemi di una configurazione aerodinamica

$$F_A = (F_A)_{WBV} + (F_A)_H + (F_A)_I$$

Concetti introduttivi

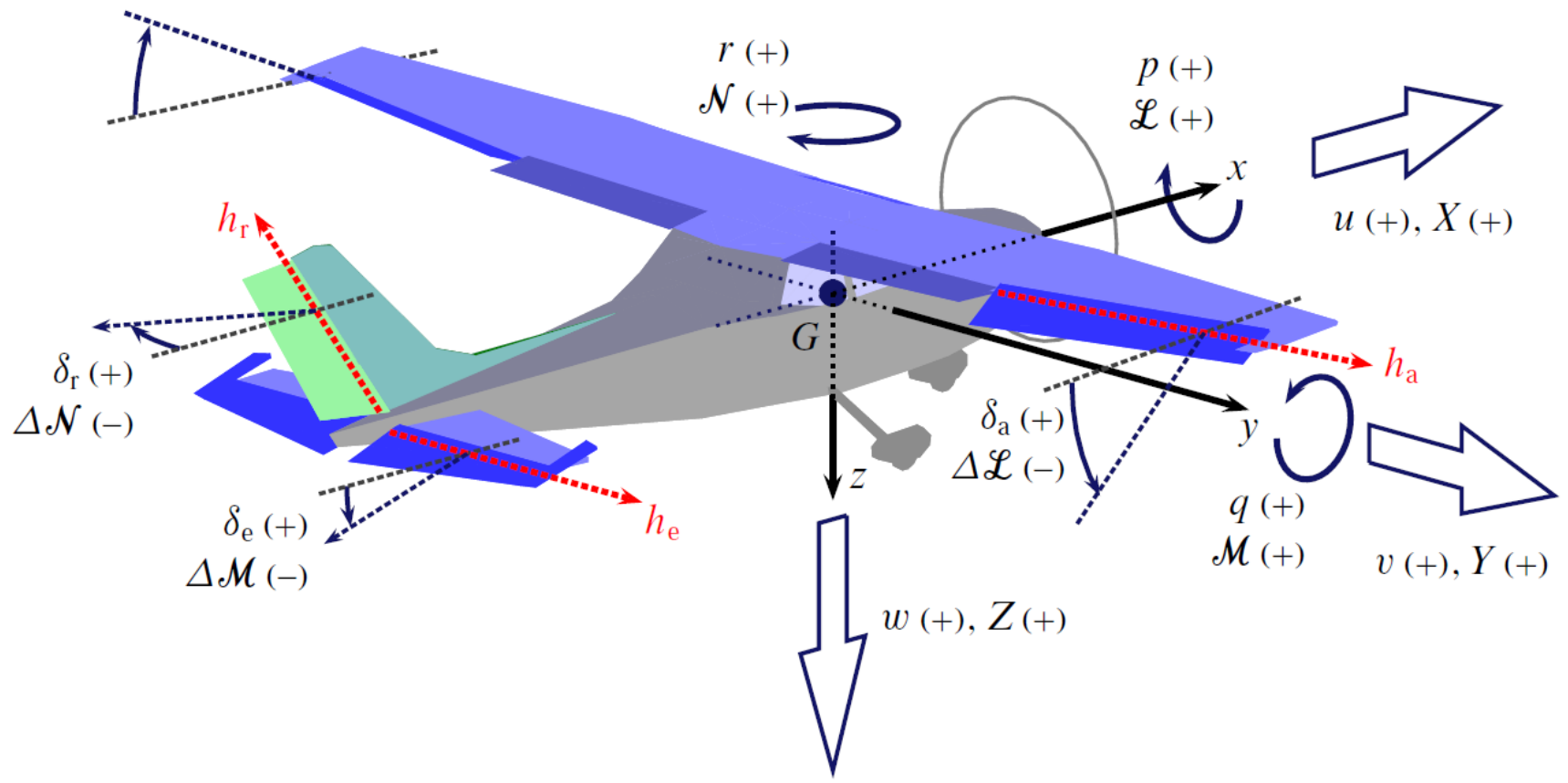
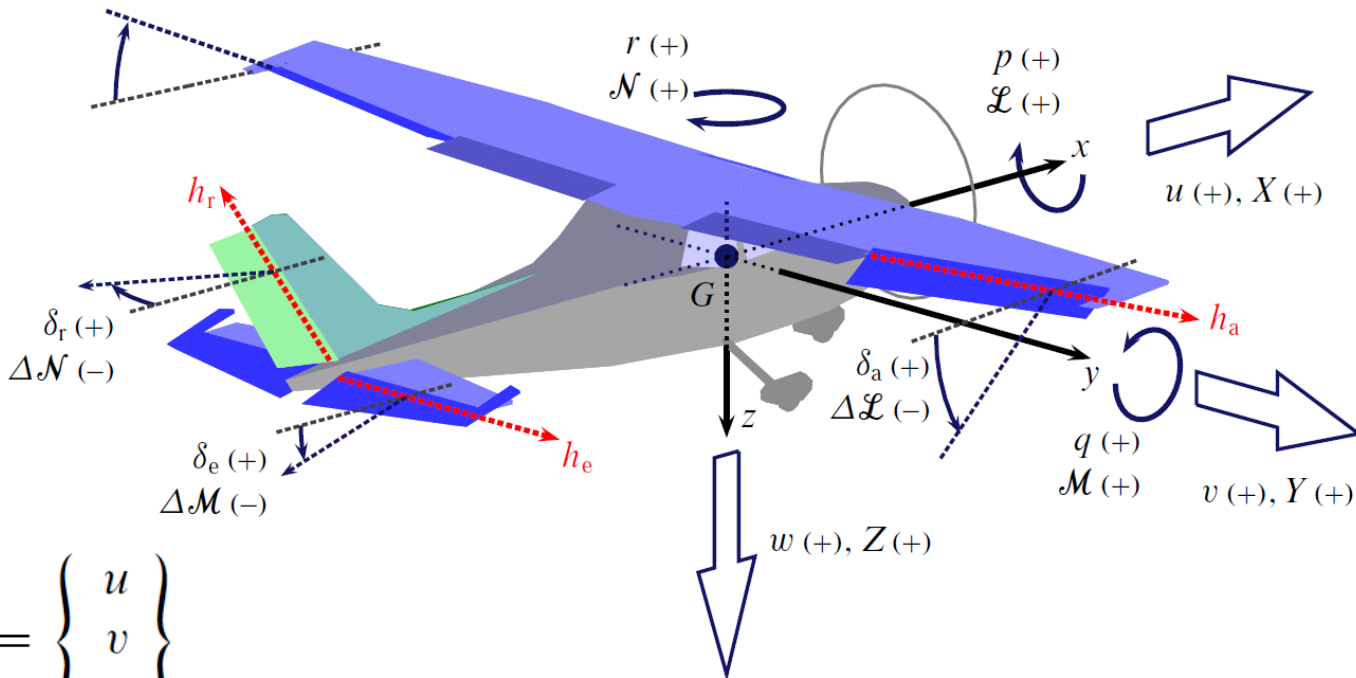


Figura 1.4 Sistema di assi velivolo e convenzioni sui segni.

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

Convenzioni



$$\mathbf{V} = u \mathbf{i} + v \mathbf{j} + w \mathbf{k} = \begin{pmatrix} u \\ v \\ w \end{pmatrix}$$

$$\mathbf{\Omega} = p \mathbf{i} + q \mathbf{j} + r \mathbf{k} = \begin{pmatrix} p \\ q \\ r \end{pmatrix}$$

$$\mathbf{F}_A + \mathbf{F}_T + \mathbf{F}_G$$

$$\mathbf{M}_A + \mathbf{M}_T$$

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

Convenzioni sulle azioni di comando

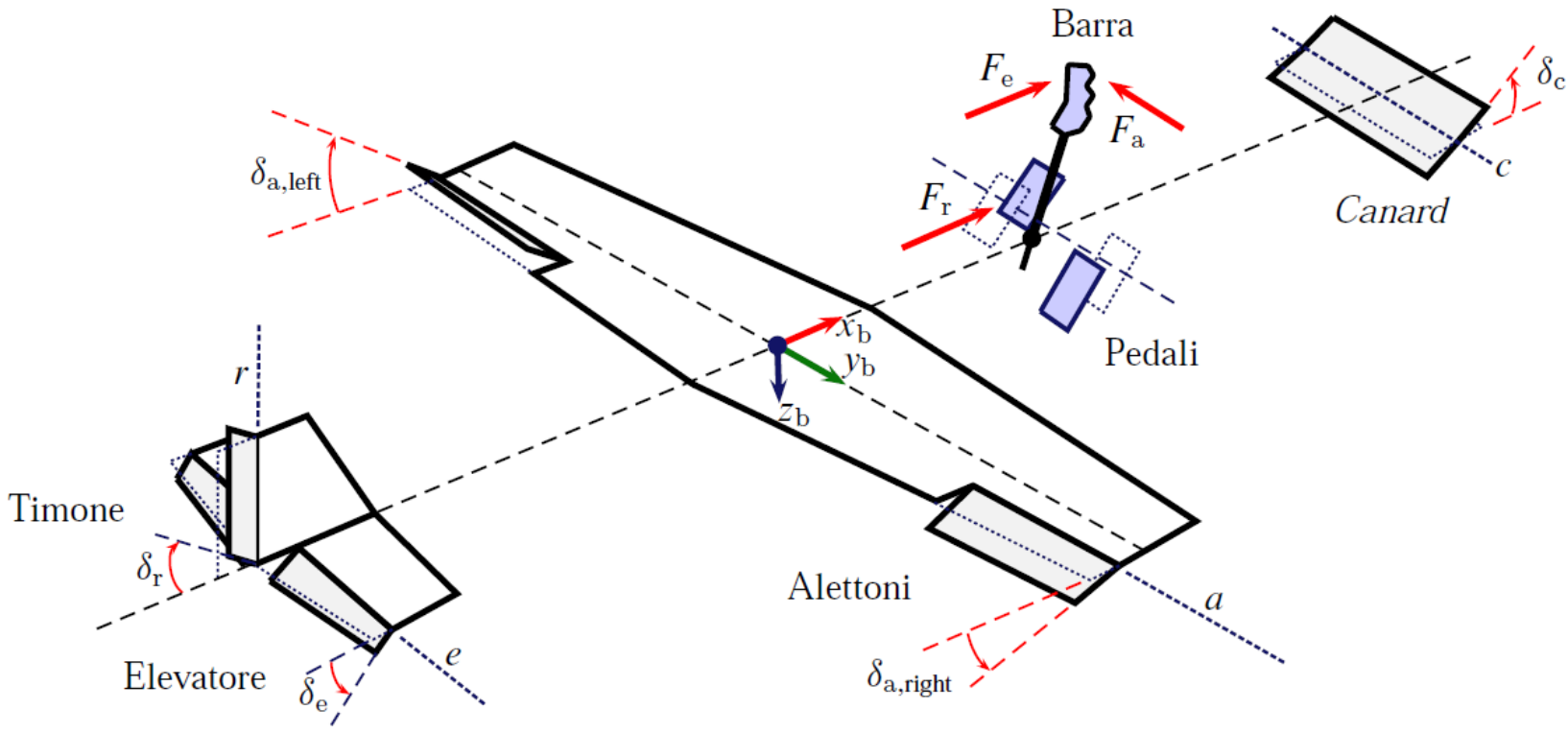


Figura 1.7 Forze positive applicate dal pilota secondo la convenzione europea e relazione con le convenzioni sui segni delle deflessioni delle superfici di governo.

Organi di governo

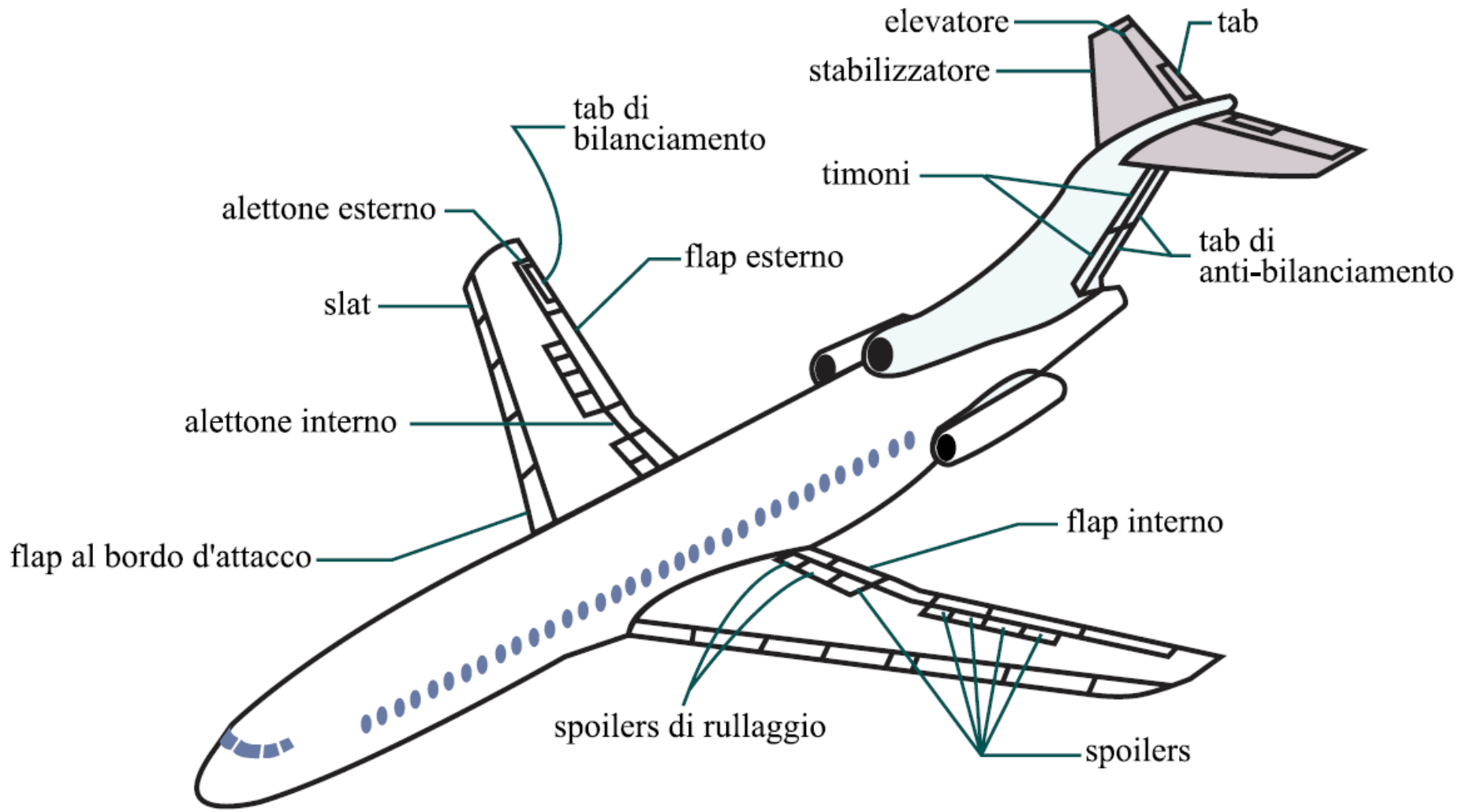
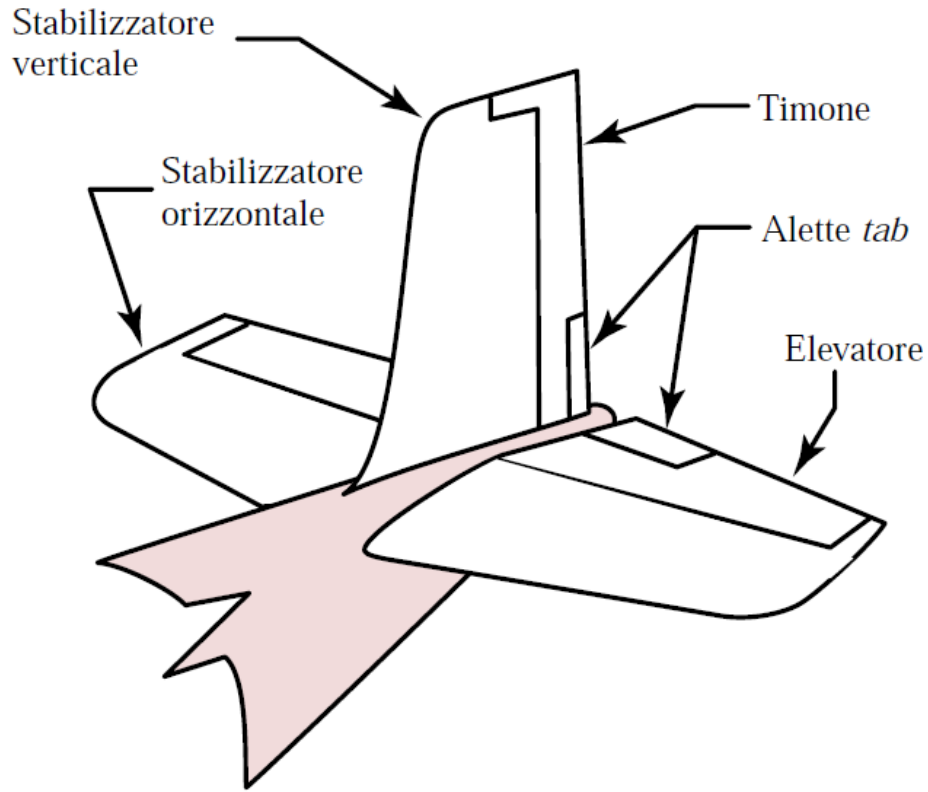
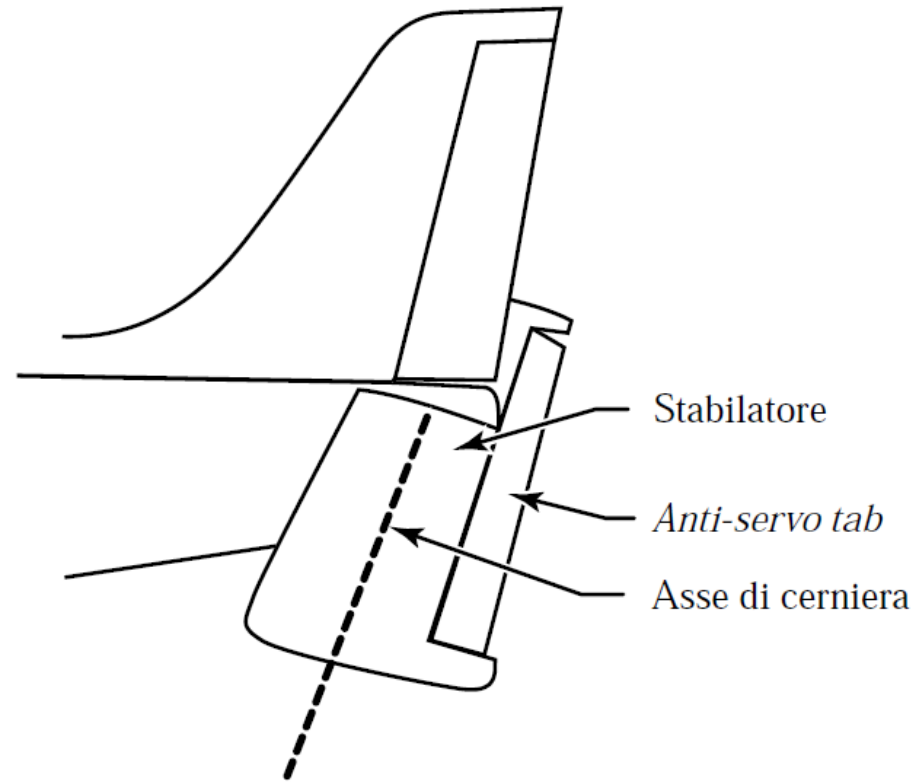


Figura 1.10 Superfici di governo di un velivolo da trasporto commerciale.

Impennaggi tradizionali



(a) Elevatore e timone di direzione.



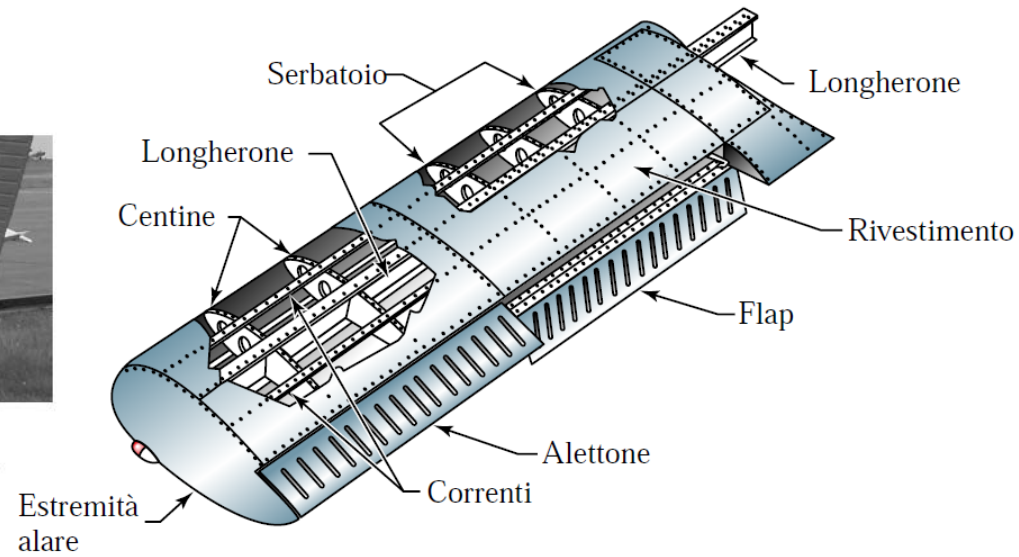
(b) Stabilizzatore.

Figura 1.6 Tipici elementi funzionali di impennaggi di coda tradizionali.

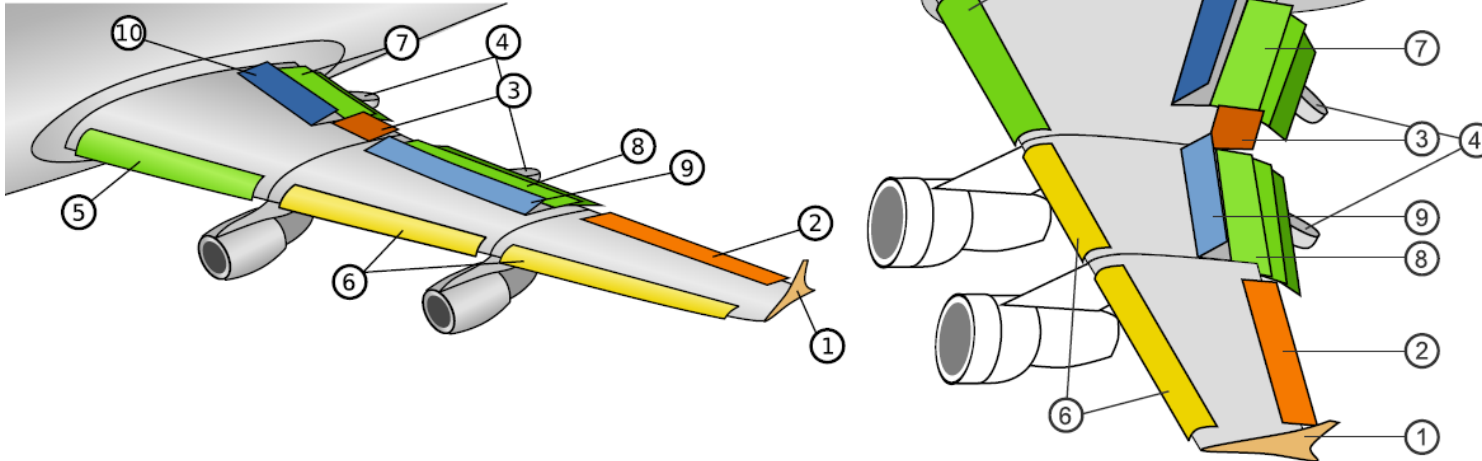
Alettoni, spoiler, ...



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

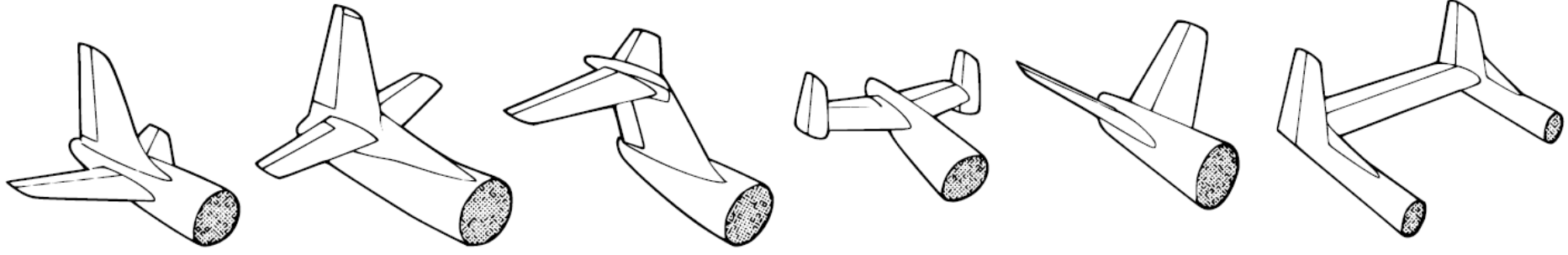


(b) Tipica struttura alare di un velivolo dell'aviazione generale.



(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

$$C_X = \frac{X}{\bar{q}S} \quad C_Y = \frac{Y}{\bar{q}S} \quad C_Z = \frac{Z}{\bar{q}S}$$
$$C_{\mathcal{L}} = \frac{\mathcal{L}}{\bar{q}Sb} \quad C_{\mathcal{M}} = \frac{\mathcal{M}}{\bar{q}Sc} \quad C_{\mathcal{N}} = \frac{\mathcal{N}}{\bar{q}Sb}$$

\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,

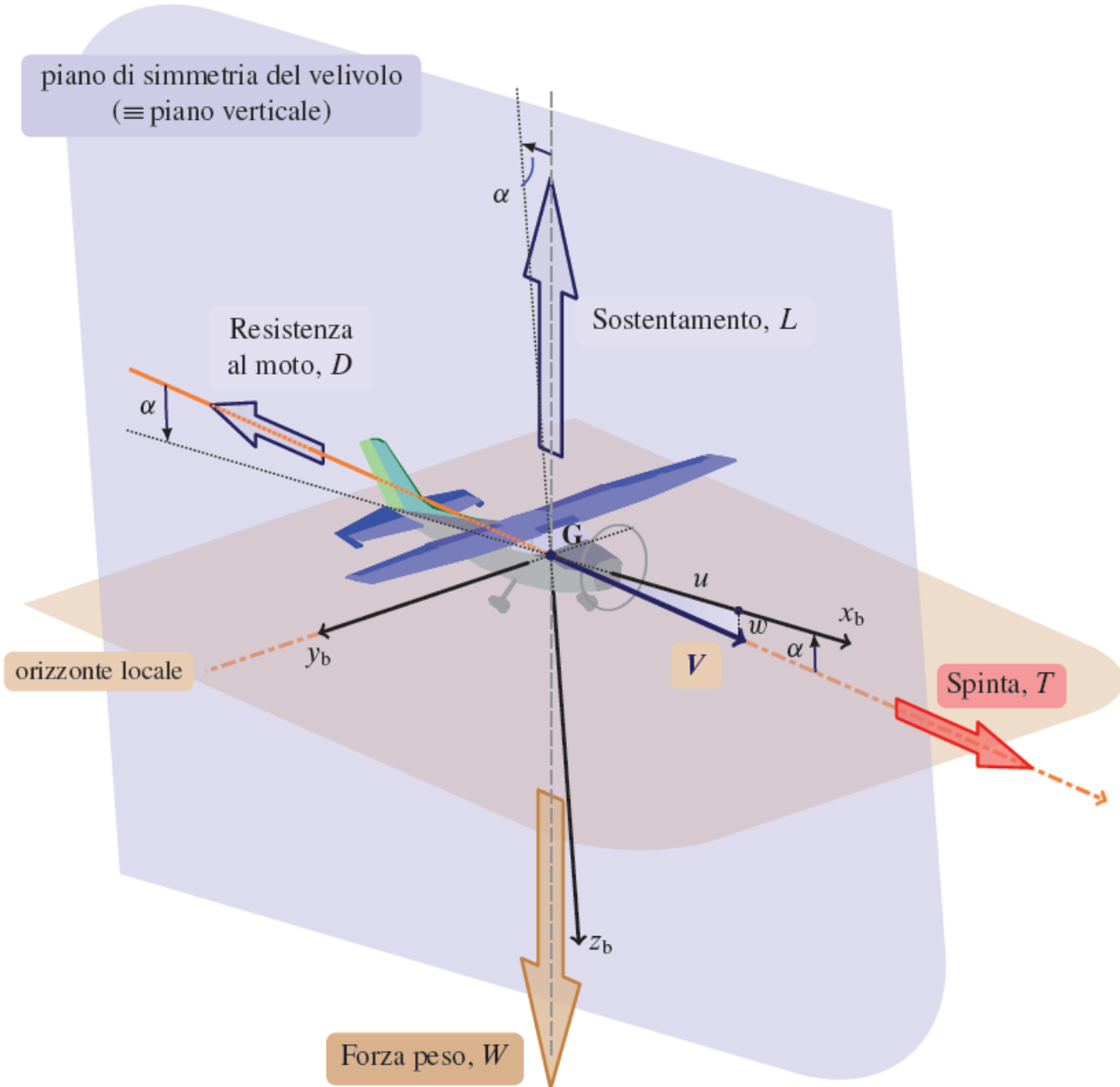
γ = rapporto dei calori specifici dell'aria (= 1,4),

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

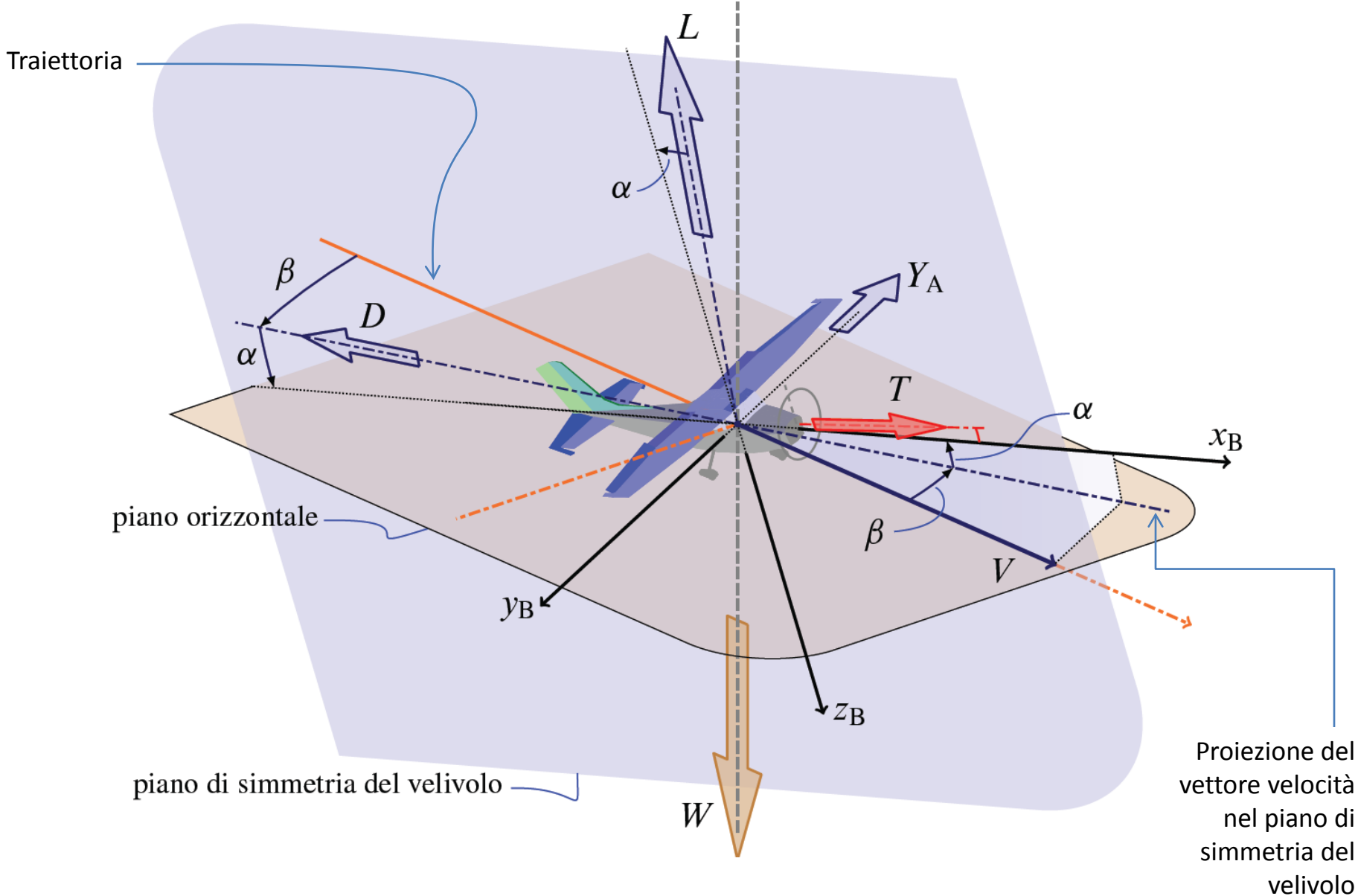
b = apertura alare di riferimento,

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

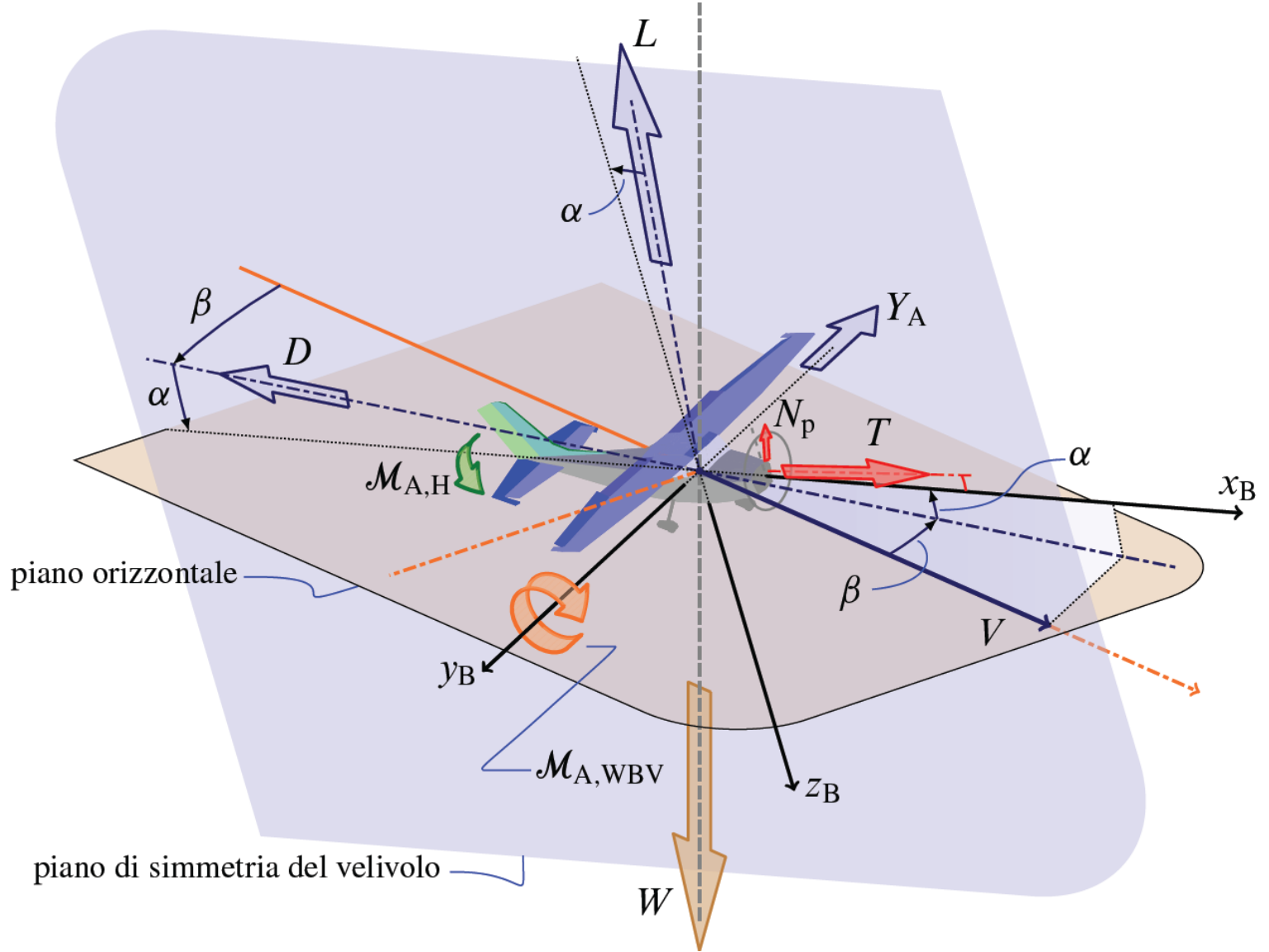
Le 4 forze della Meccanica del volo



Crabbing (volo asimmetrico)



Crabbing (volo asimmetrico)

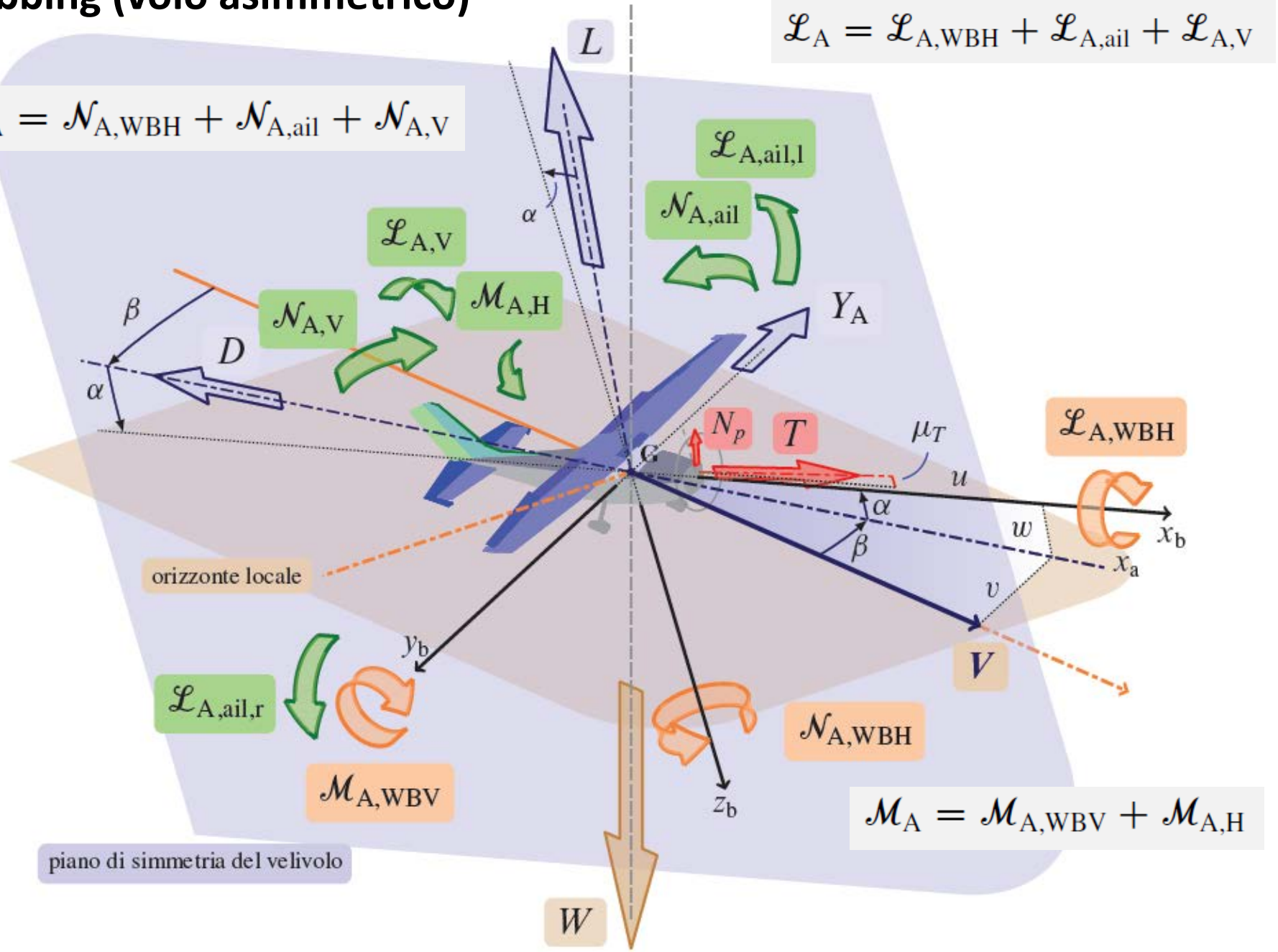


Crabbing (volo asimmetrico)

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

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

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



Crabbing (volo asimmetrico)



Riduzione dei sistemi di forze

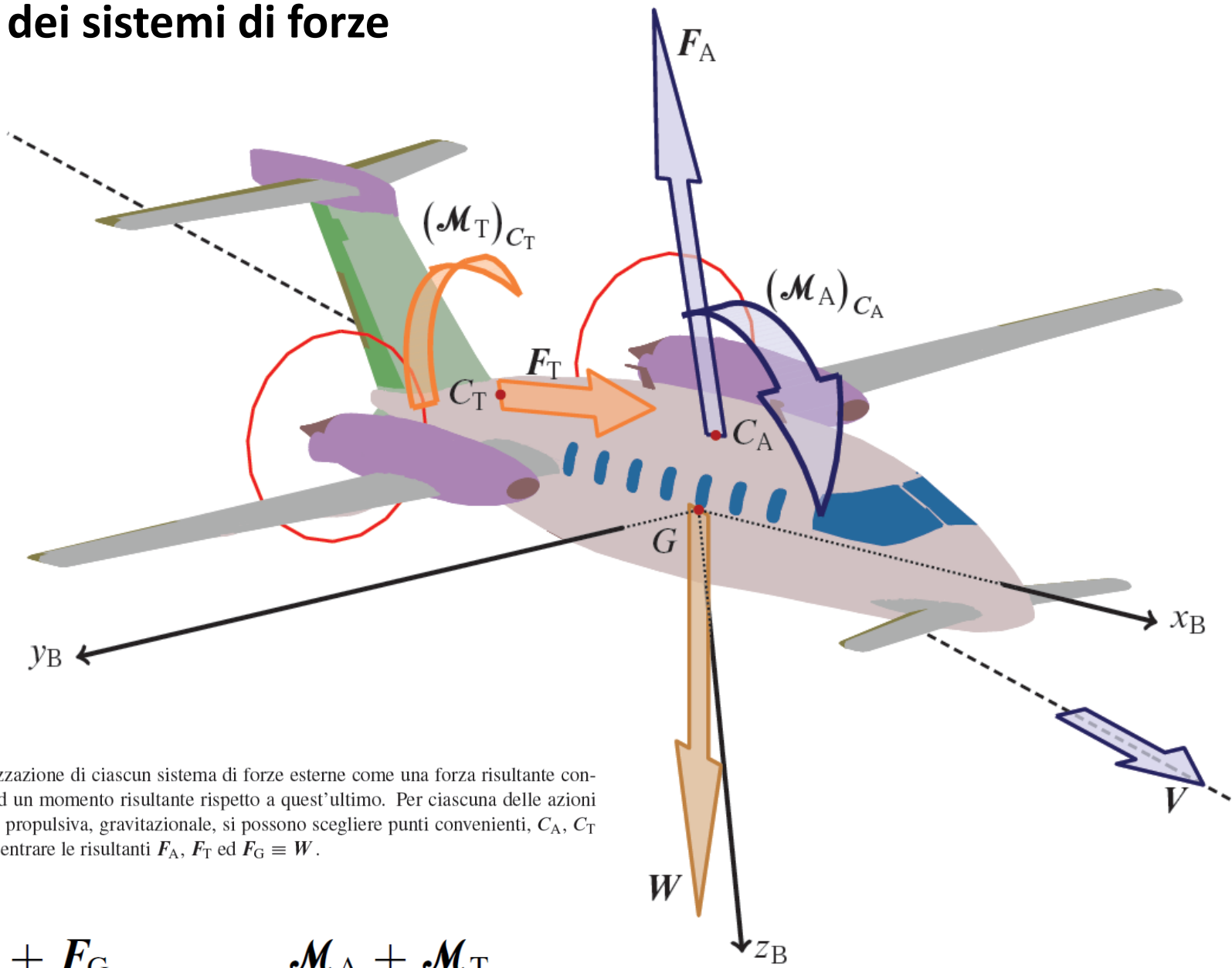


Figura 1.13 Schematizzazione di ciascun sistema di forze esterne come una forza risultante concentrata in un punto ed un momento risultante rispetto a quest'ultimo. Per ciascuna delle azioni esterne, aerodinamica, propulsiva, gravitazionale, si possono scegliere punti convenienti, C_A , C_T e $C_G \equiv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

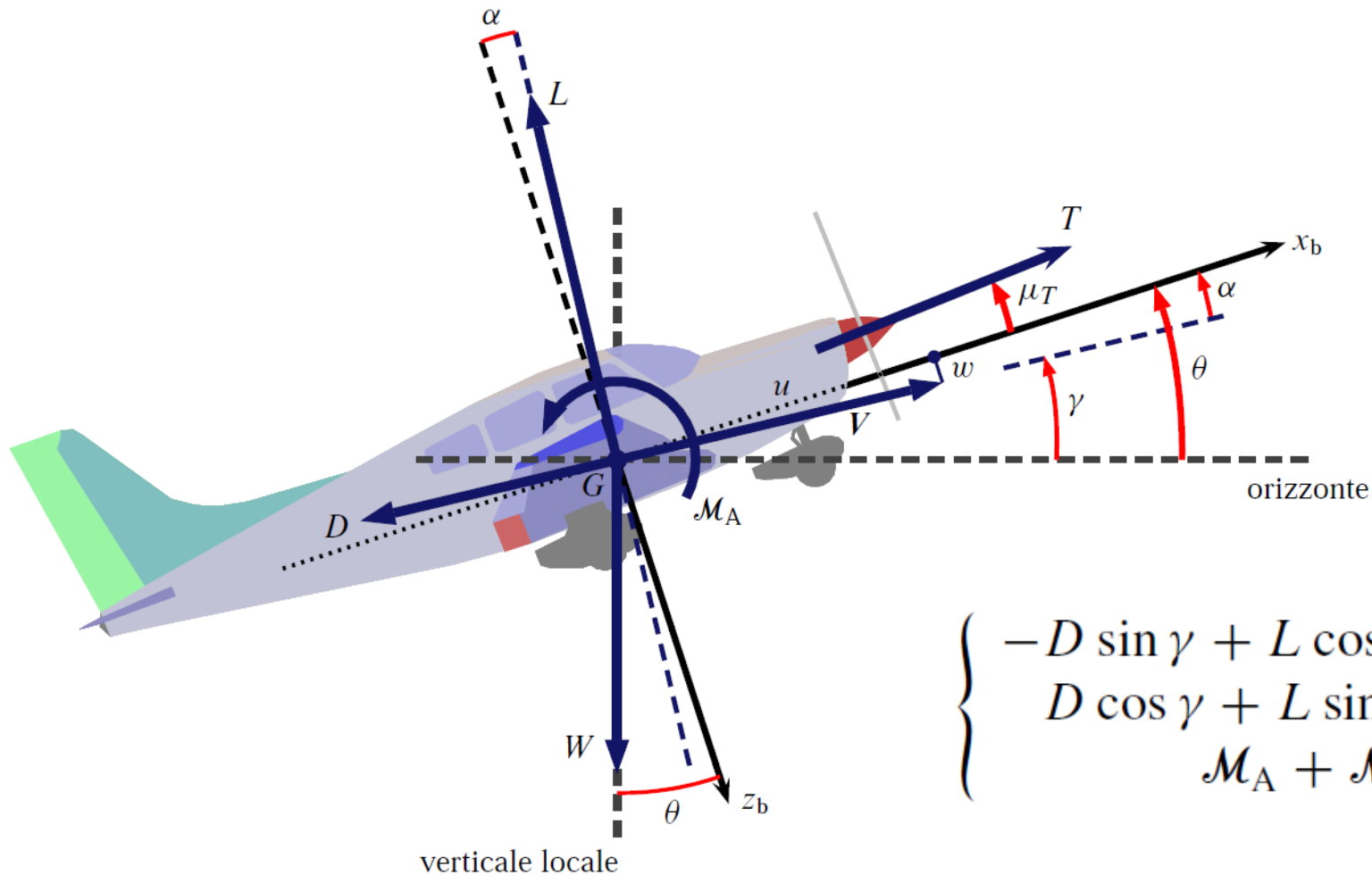
$$F_A + F_T + F_G$$

$$M_A + M_T$$

Volo equilibrato

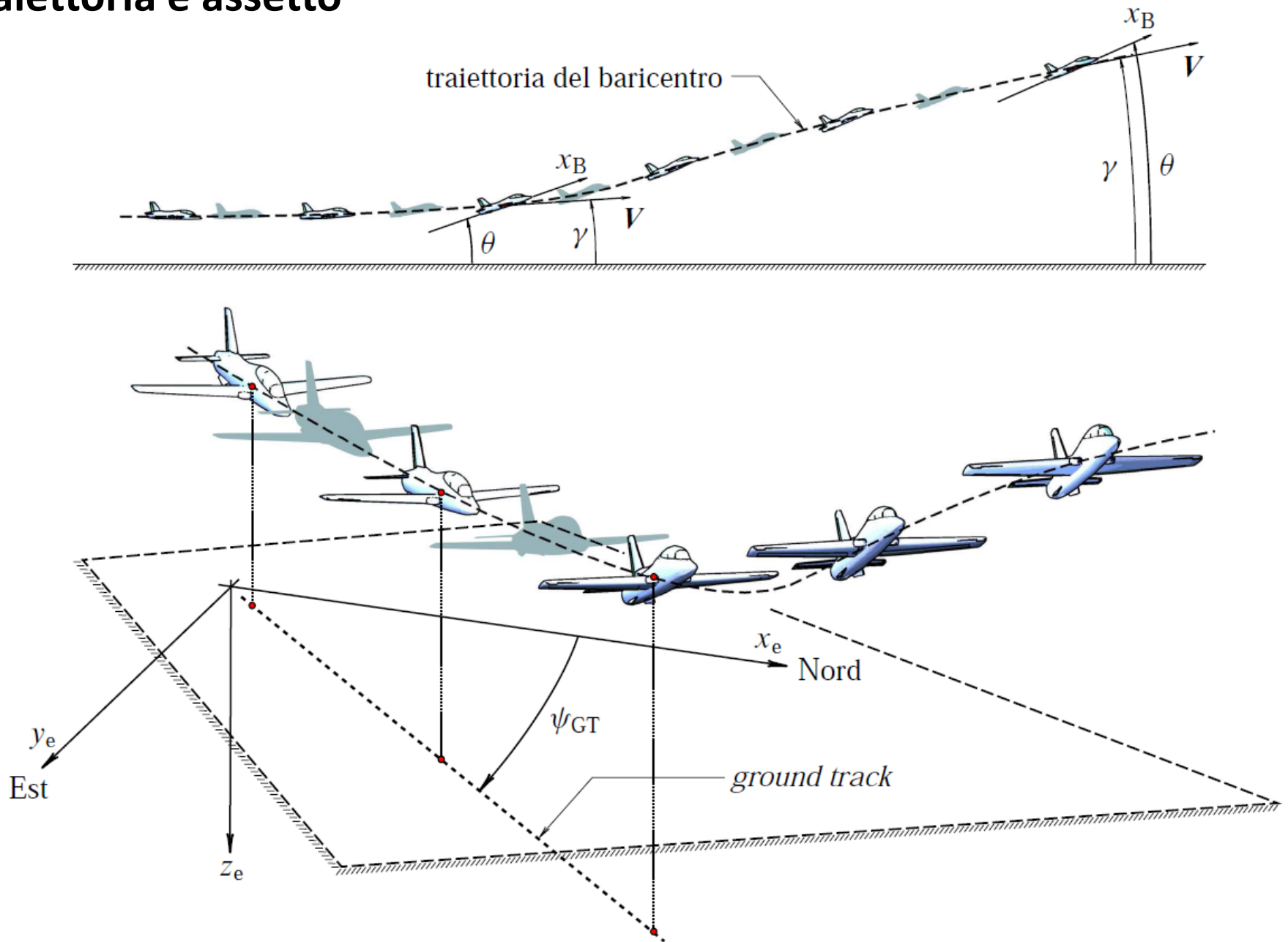
$$0 = (X_G + X_A + X_T) \mathbf{i} + (Y_G + Y_A + Y_T) \mathbf{j} + (Z_G + Z_A + Z_T) \mathbf{k}$$

$$\mathcal{L}_A + \mathcal{L}_T = 0, \quad \mathcal{M}_A + \mathcal{M}_T = 0, \quad \mathcal{N}_A + \mathcal{N}_T = 0$$



$$\left\{ \begin{array}{l} -D \sin \gamma + L \cos \gamma = W \\ D \cos \gamma + L \sin \gamma = T \\ \mathcal{M}_A + \mathcal{M}_T = 0 \end{array} \right.$$

Traiettoria e assetto



Concetti introduttivi



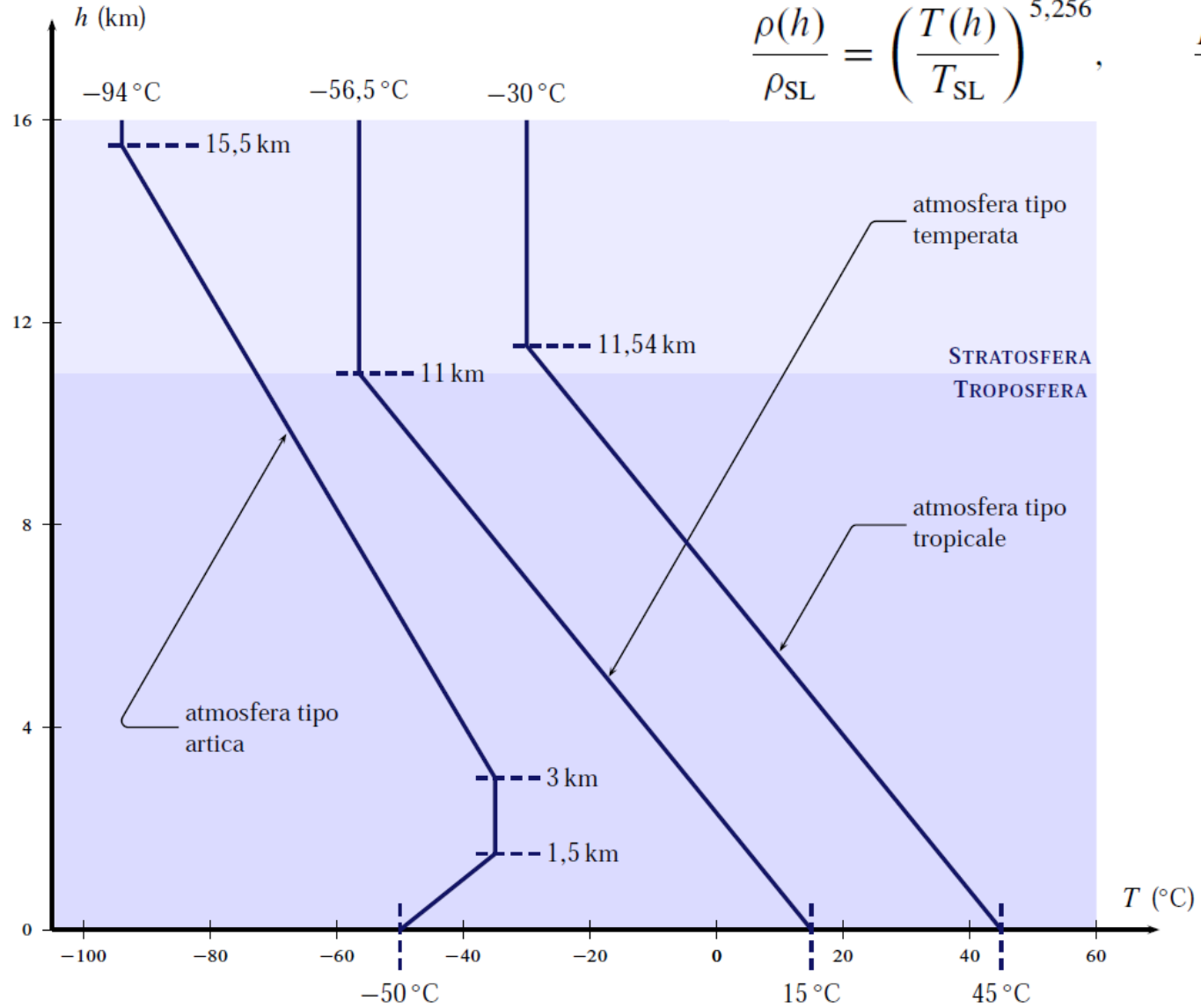
Concetti introduttivi



Modello di atmosfera, ISA

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

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



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 N m ⁻²	2116,2 lb
Densità, ρ_{SL}	1,225 kg m ⁻³	0,002 377 slug ft ⁻³
Temperatura, T_{SL}	15,0 °C	518,67 °R 59,0 °F
Velocità del suono, a_{SL}	340,3 m s ⁻¹ 1225 km h ⁻¹	116,4 ft s ⁻¹
Viscosità dinamica, μ_{SL}	$5,7571 \cdot 10^{-9}$ N s m ⁻²	$3,7373 \cdot 10^{-7}$ lb s ft ⁻²
Gradiente ^a termico verticale, $(dT/dz_e)_{SL}$	$6,5 \cdot 10^{-3}$ °C m ⁻¹	
Gradiente ^a barico verticale, $(dp/dz_e)_{SL}$	11,72 Pa m ⁻¹	

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

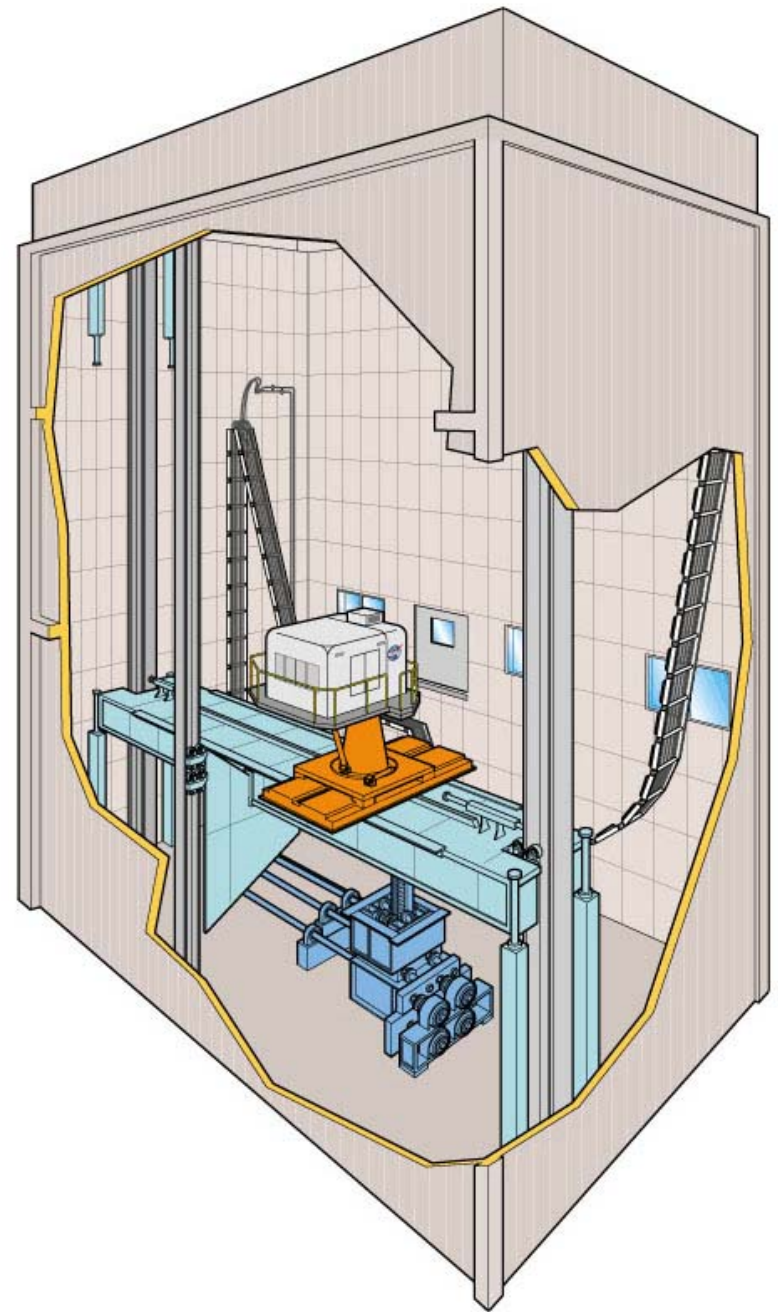
Concetti introduttivi



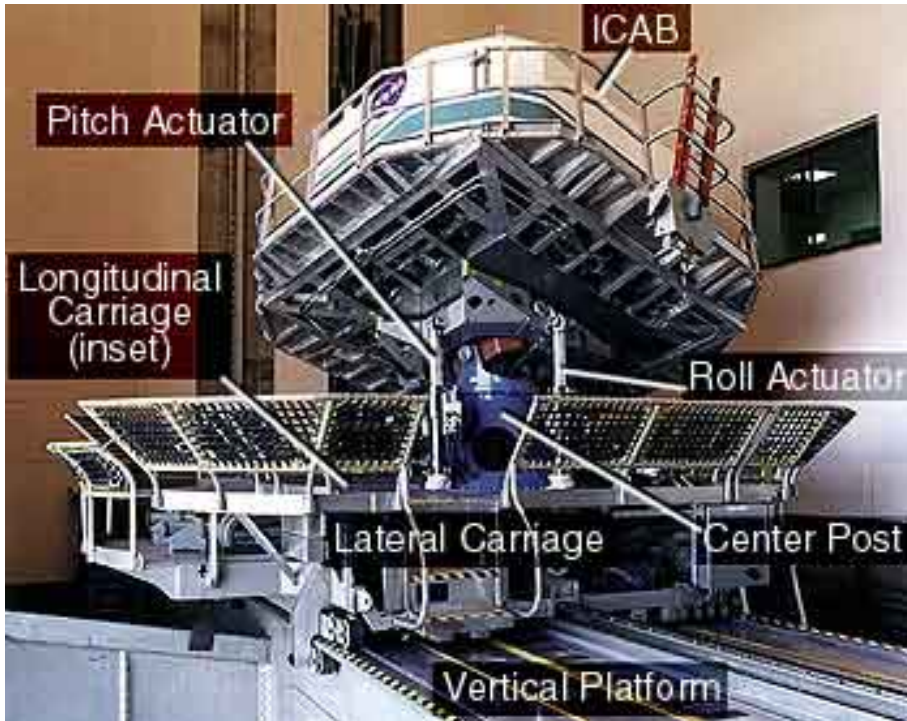
Volo in atmosfera



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

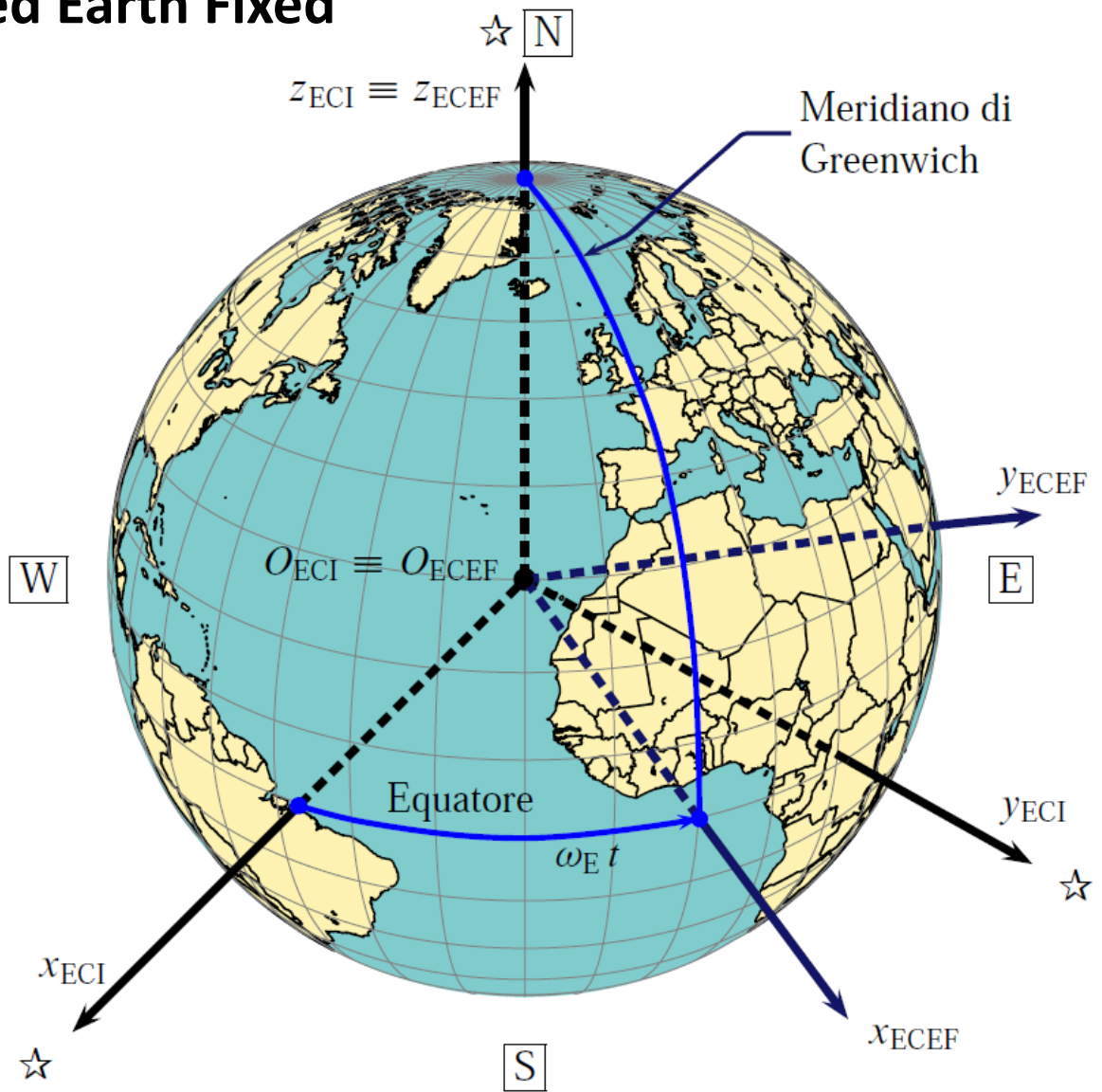


Figura 1.1 Riferimento inerziale \mathcal{T}_{ECI} e riferimento solidale alla Terra \mathcal{T}_{ECR} .

Geodesia

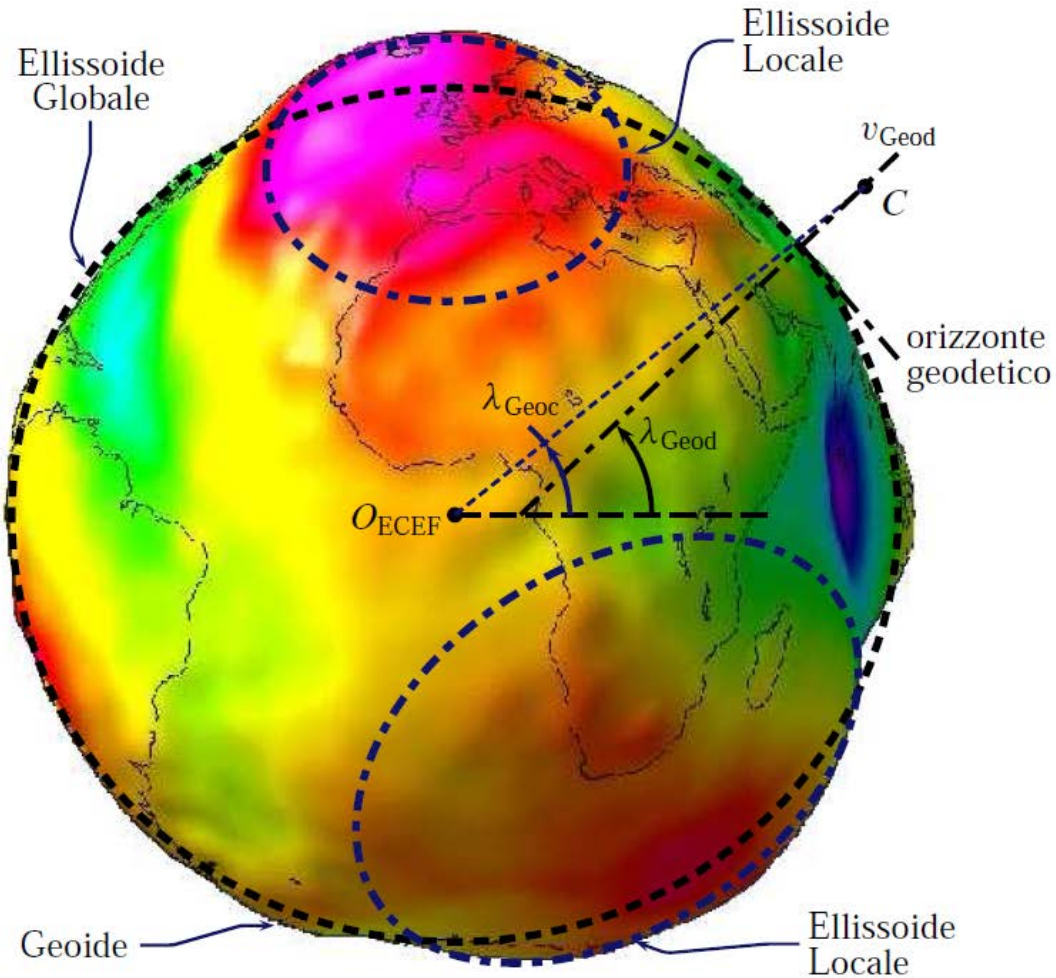


Figura 1.2 Geoide terrestre, ellissoide globale, ed ellissoidi locali. Nella rappresentazione tridimensionale i discostamenti dei punti del geoida dall'ellissoide globale sono amplificati di un fattore di ordine 10^5 .

Modelli geodetici

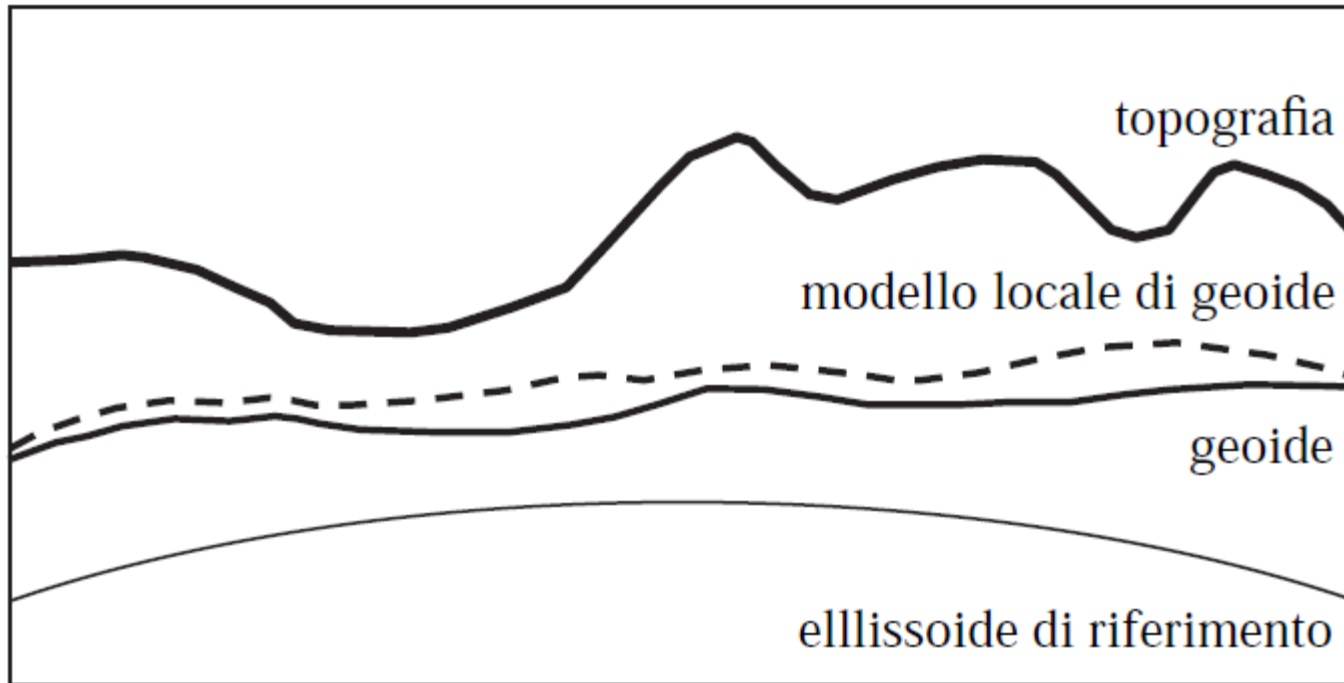


Figura 1.3 Profilo topografico e geoide globale. Spesso il geoide è approssimato localmente da un modello locale di geoide oppure da un ellissoide locale di riferimento.

Geoide, ellissoidi approssimanti

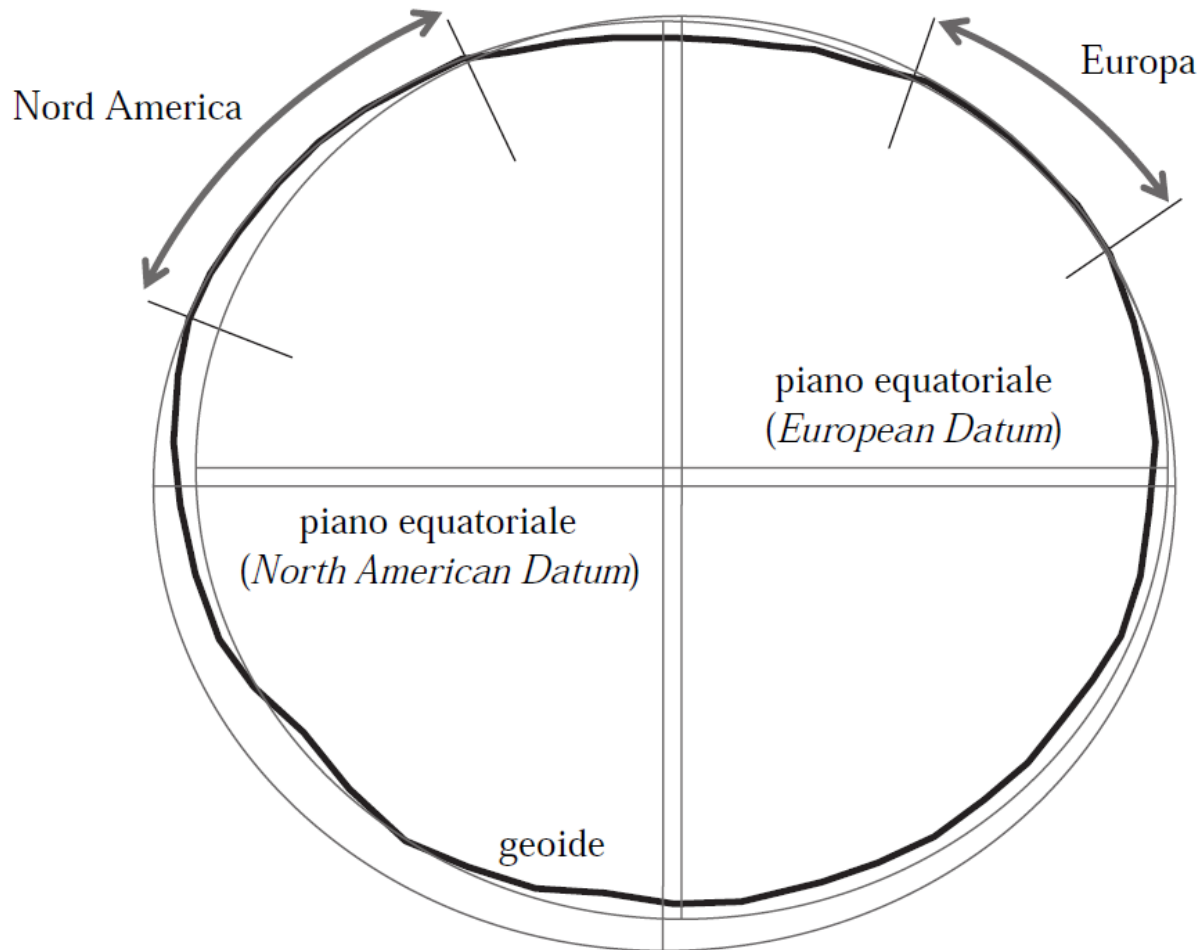


Figura 1.4 Profilo del geoide globale ed ellissoidi locali di riferimento.

Modelli geodetici, WGS84

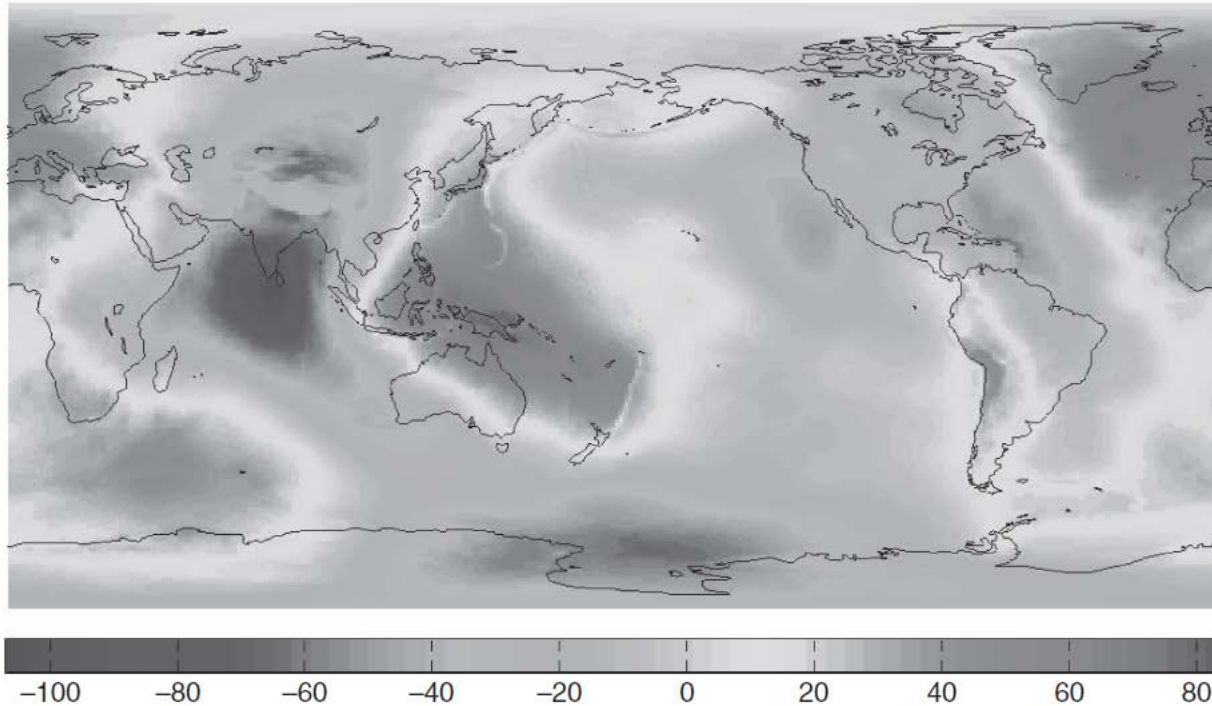


Figura 1.5 Discostamenti (in metri) del geode dall'ellissoide di riferimento definito dal sistema WGS84.

Latitudine geodetica e geocentrica

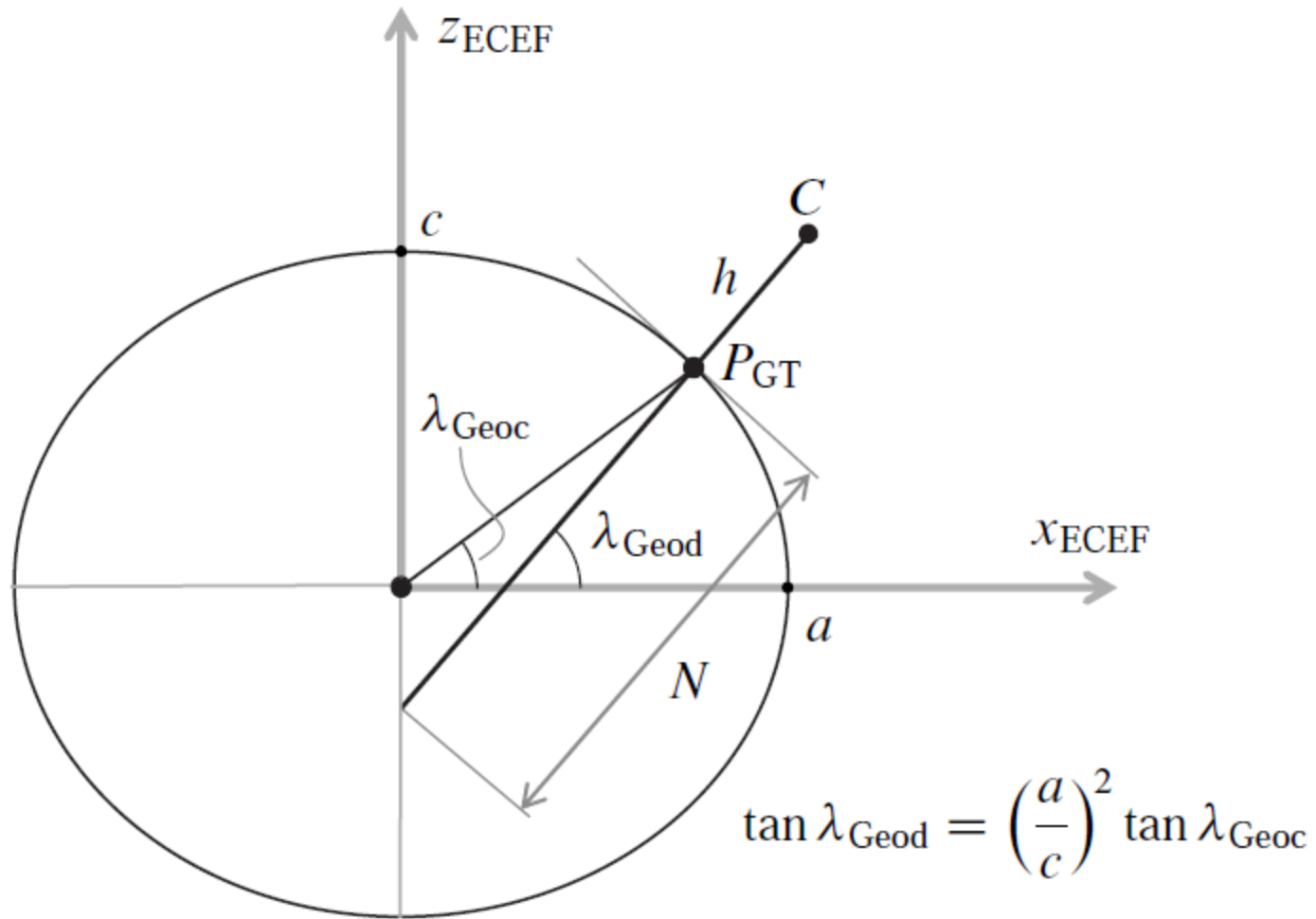


Figura 1.6 Latitudine geocentrica e geodetica.

Concetti introduttivi

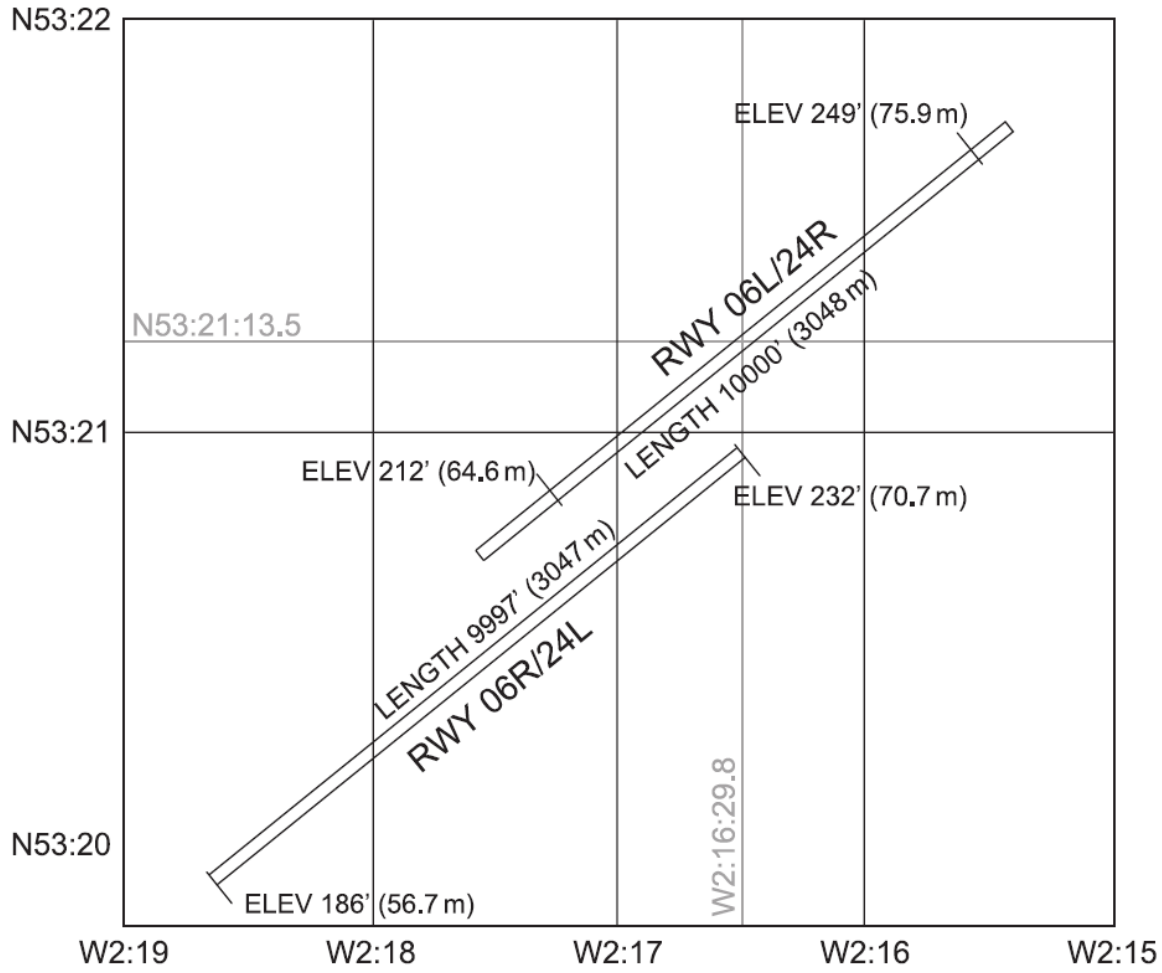


Figura 1.7 Collocazione delle piste dell'aeroporto di Manchester (sigla EGCC) ed elevazioni locali (riprodotta dal testo di Diston [8]). Elevazioni in piedi e in metri

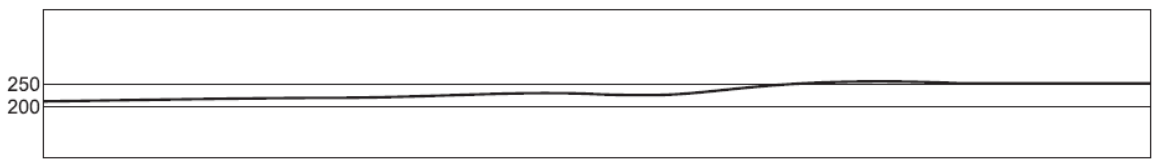


Figura 1.8 Profilo approssimativo della pista 06L/24R dell'aeroporto di Manchester (riprodotta dal testo di Diston [8]). Elevazioni in piedi.

Riferimenti tangenti, Local Vertical- -Local Horizontal

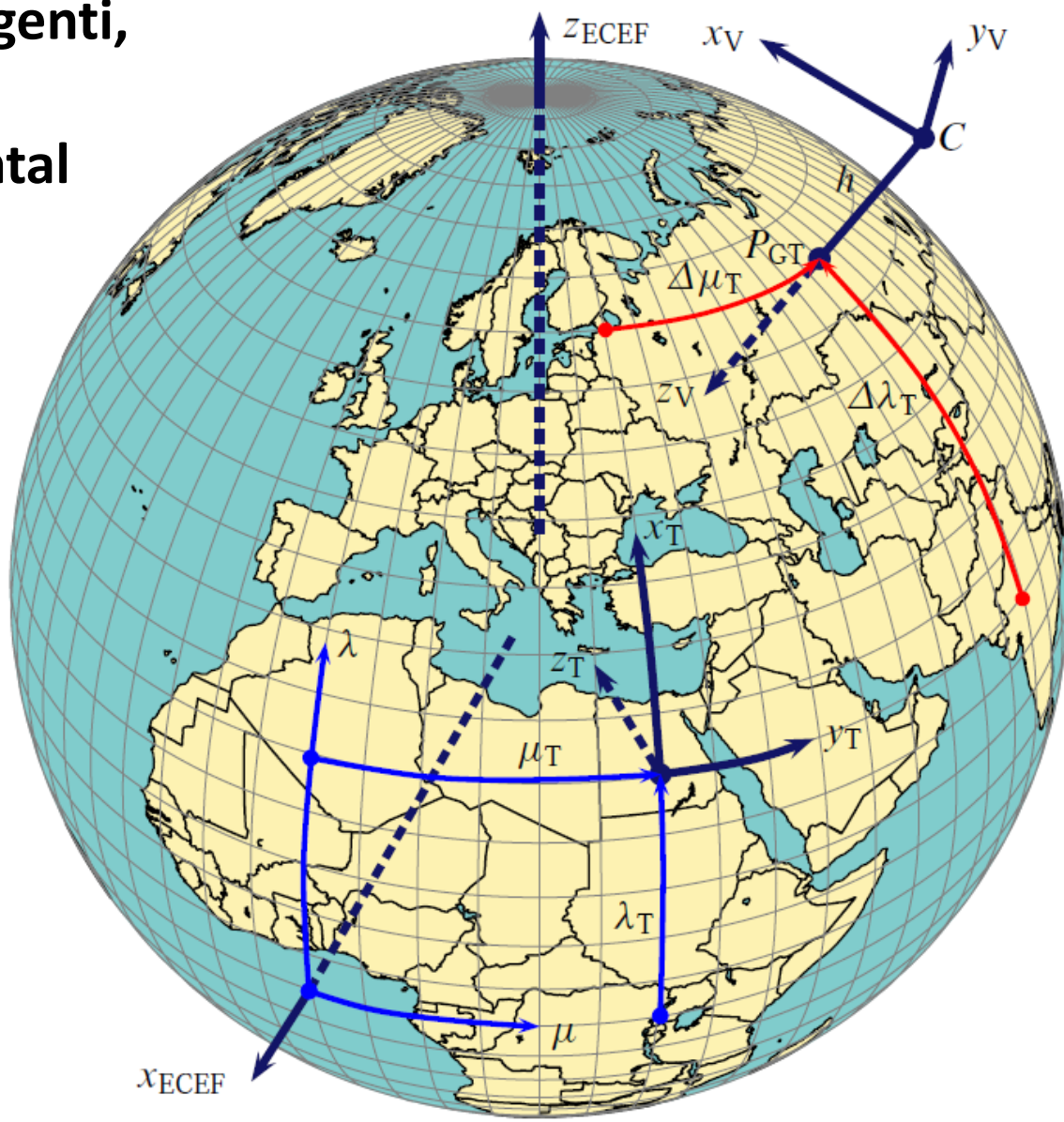


Figura 1.9 Terne di riferimento *Earth-Centered Earth-Fixed*, \mathcal{T}_{ECEF} , *Tangent*, \mathcal{T}_T , *Vehicle-Carried Vertical*, \mathcal{T}_V .

Earth frame, Flat Earth

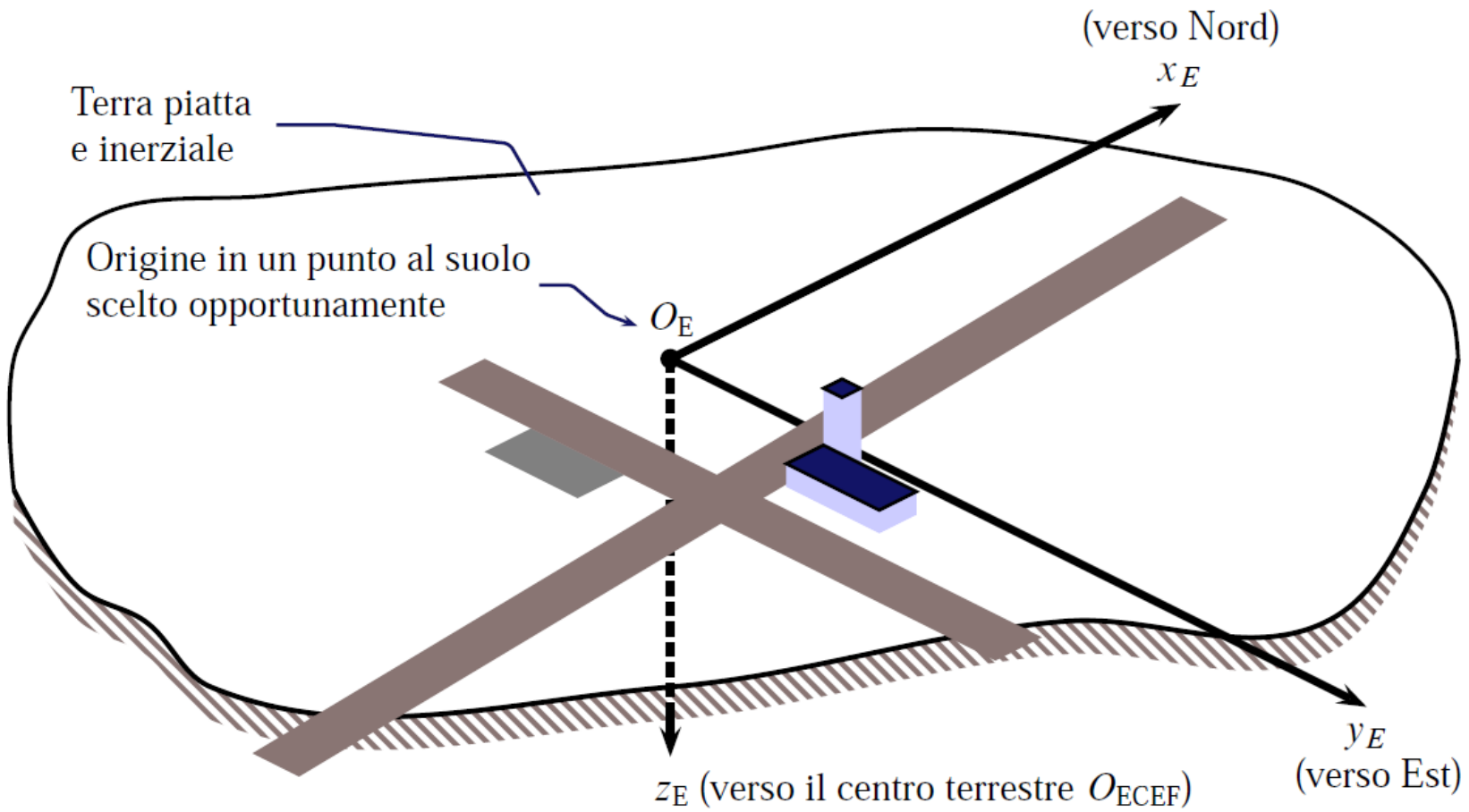


Figura 1.10 Riferimento fisso $\mathcal{T}_E \equiv \mathcal{T}_{LVLH}$ in ipotesi di Terra piatta ed inerziale.

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'atmosfera trasla macroscopicamente con velocità V_{wind} .

Posizione e orientamento del velivolo rispetto alla terra

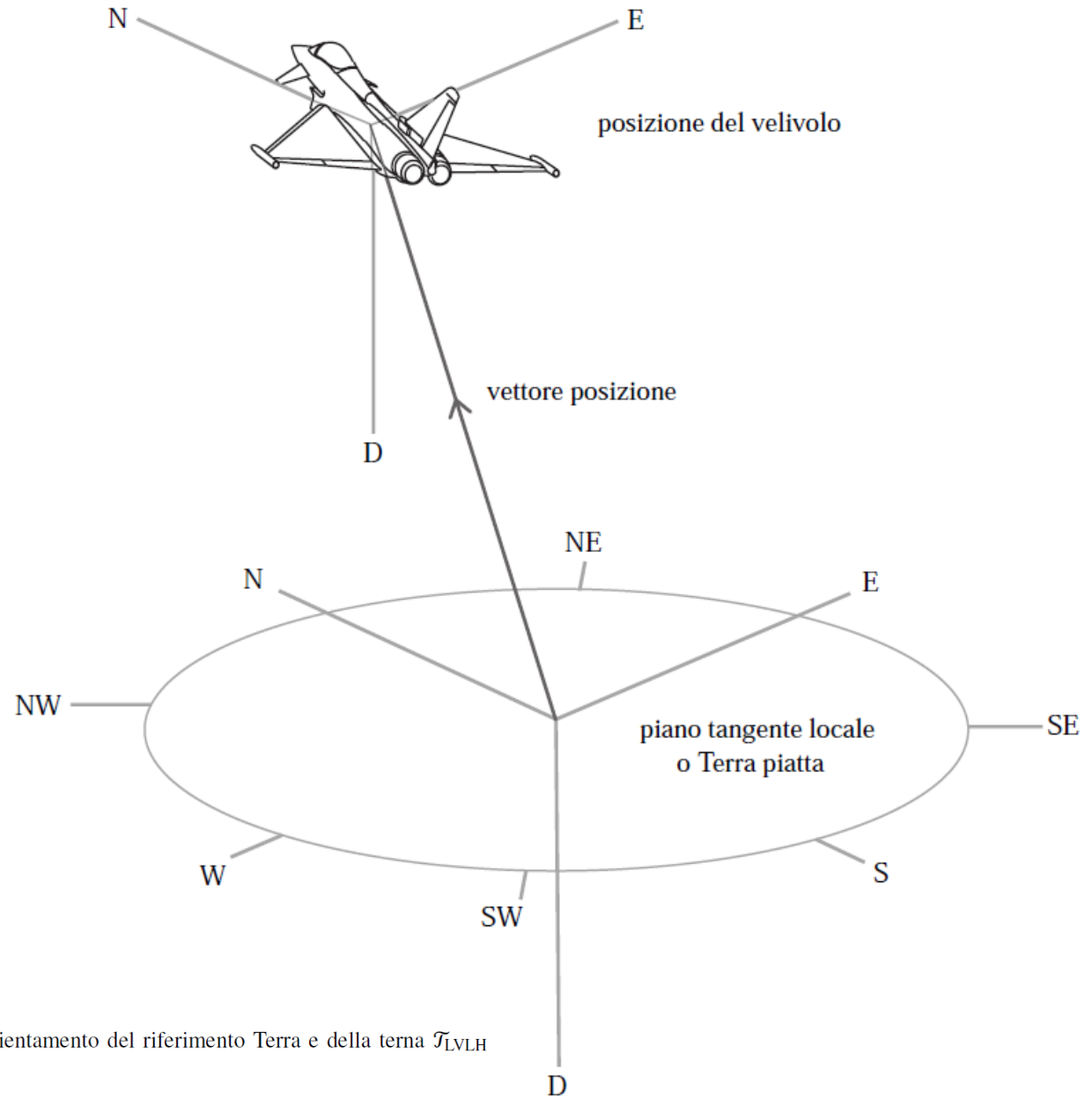


Figura 1.12 Posizione del velivolo rispetto alla Terra. Orientamento del riferimento Terra e della terna \mathcal{T}_{LVLH} secondo la convenzione *North-East-Down*.

Assi traiettoria e Wind axes

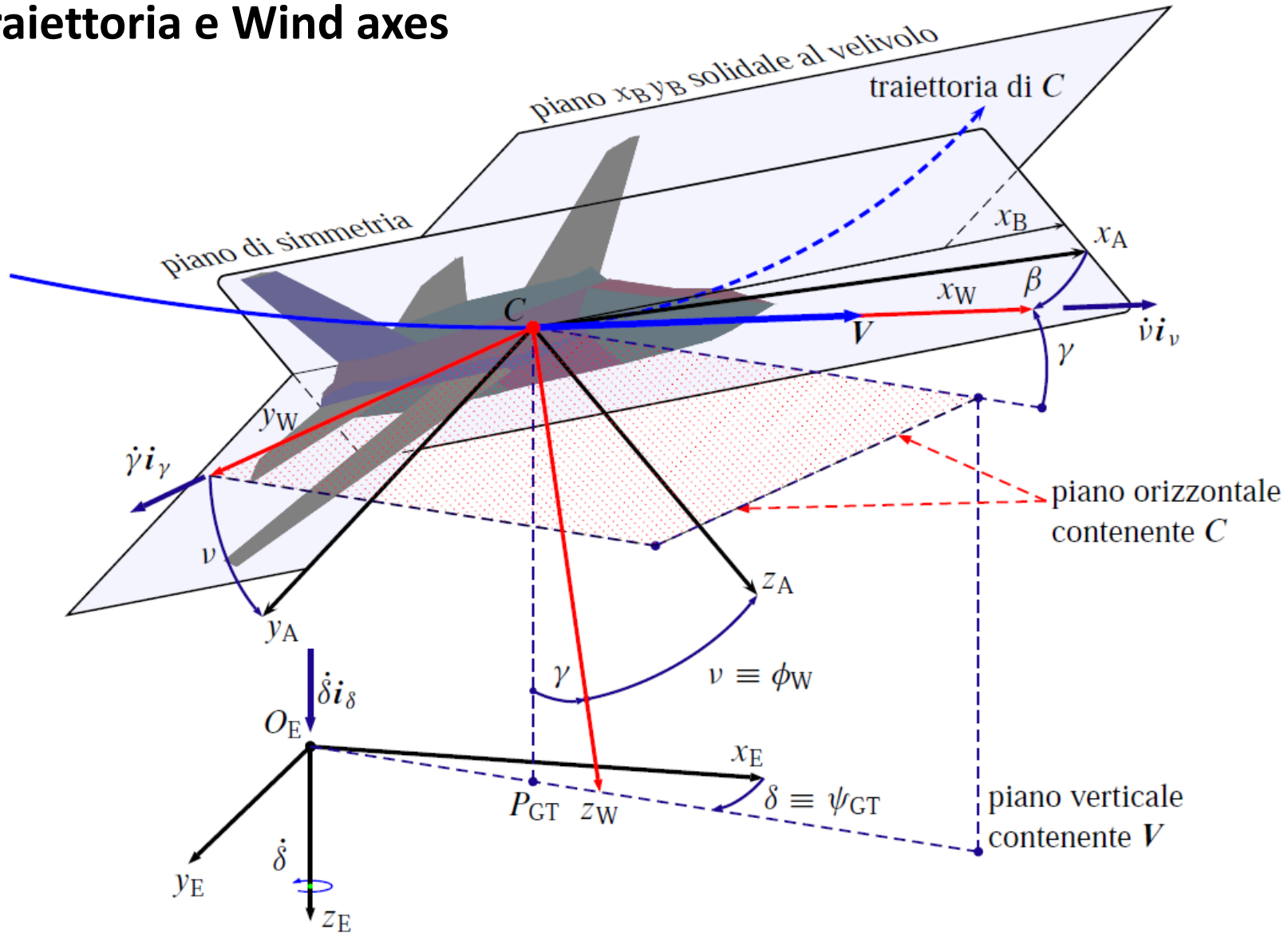


Figura 1.13 Assi vento (o assi traiettoria).

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

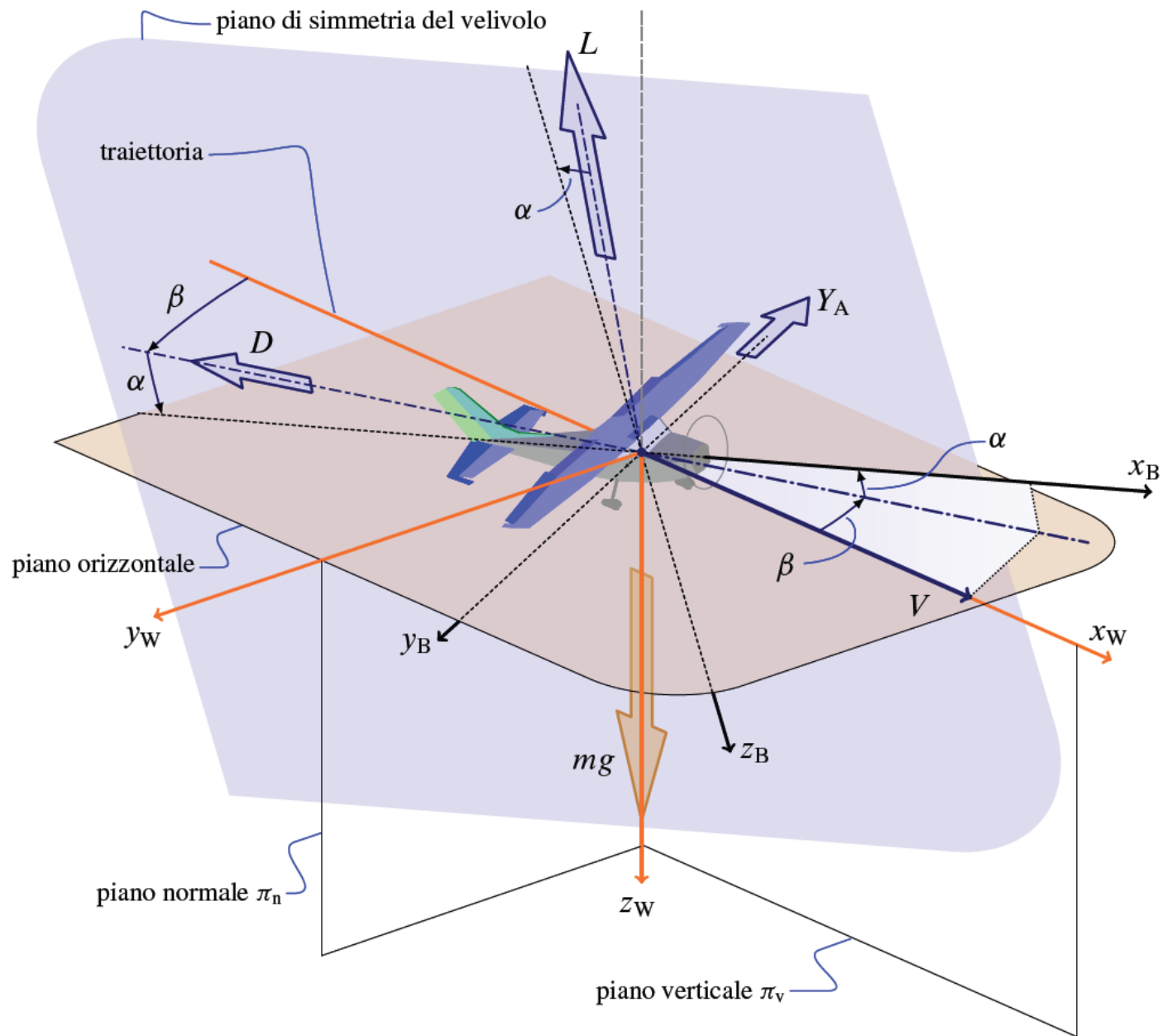


Figura 1.13 Tema di assi vento $\mathcal{T}_W = \{G, x_W, y_W, z_W\}$ (o assi traiettoria). In questa particolare circostanza la traiettoria del baricentro è orizzontale e l'orientamento del velivolo non è simmetrico rispetto al piano verticale $x_W z_W$.

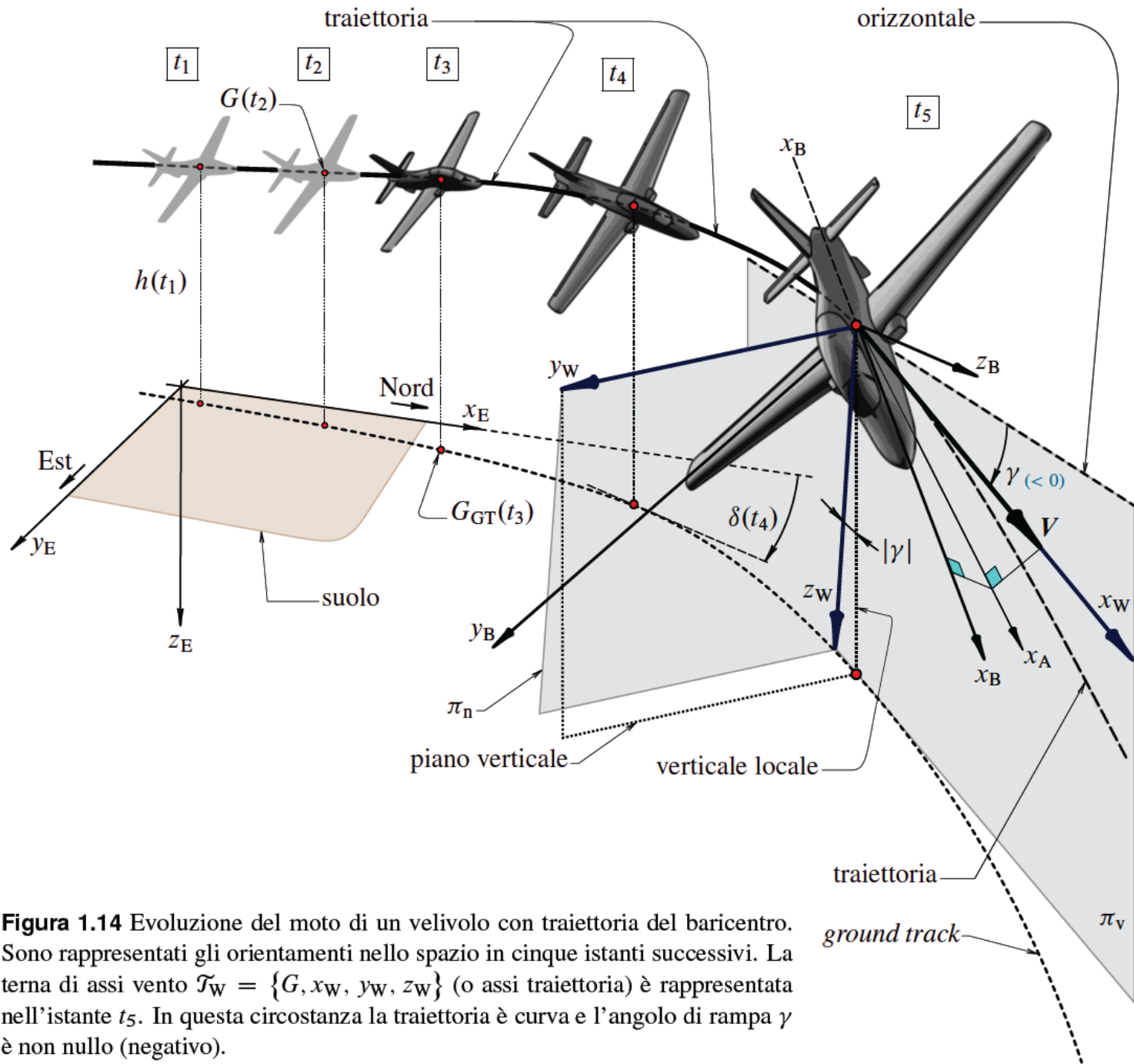


Figura 1.14 Evoluzione del moto di un velivolo con traiettoria del baricentro. Sono rappresentati gli orientamenti nello spazio in cinque istanti successivi. La terna di assi vento $\mathcal{T}_W = \{G, x_W, y_W, z_W\}$ (o assi traiettoria) è rappresentata nell'istante t_5 . In questa circostanza la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

Velocità angolare istantanea



Velocità angolare istantanea

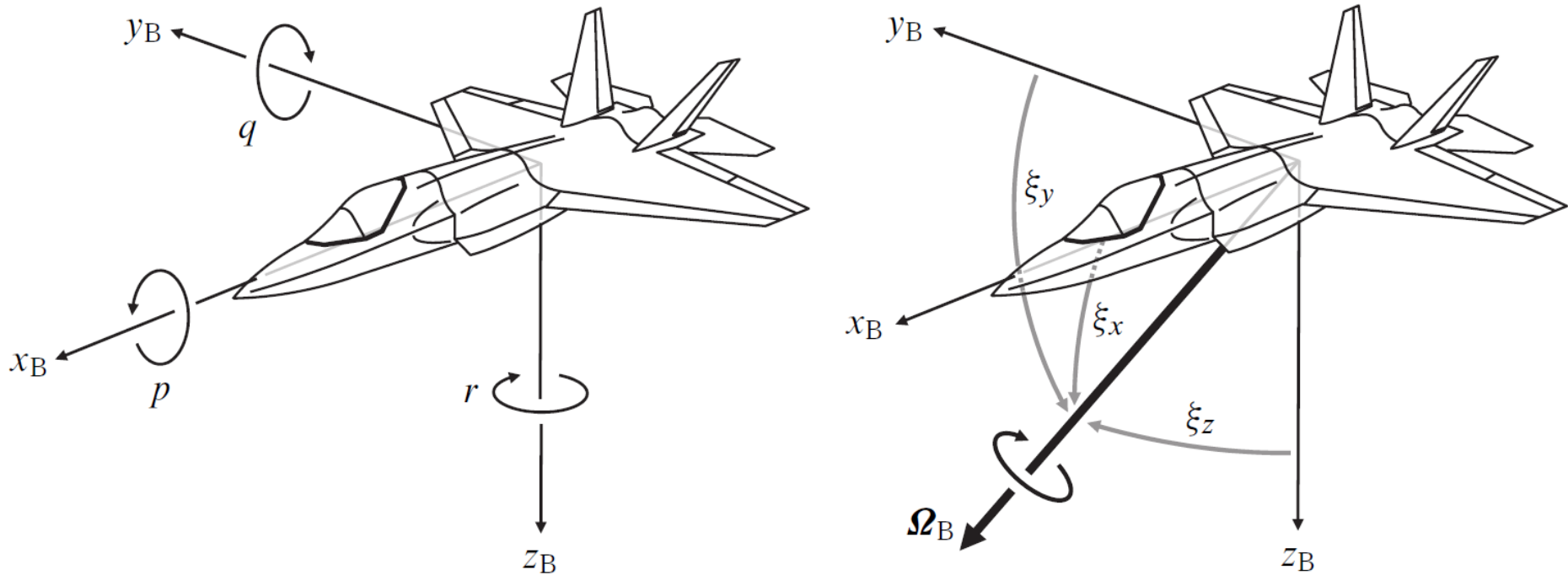


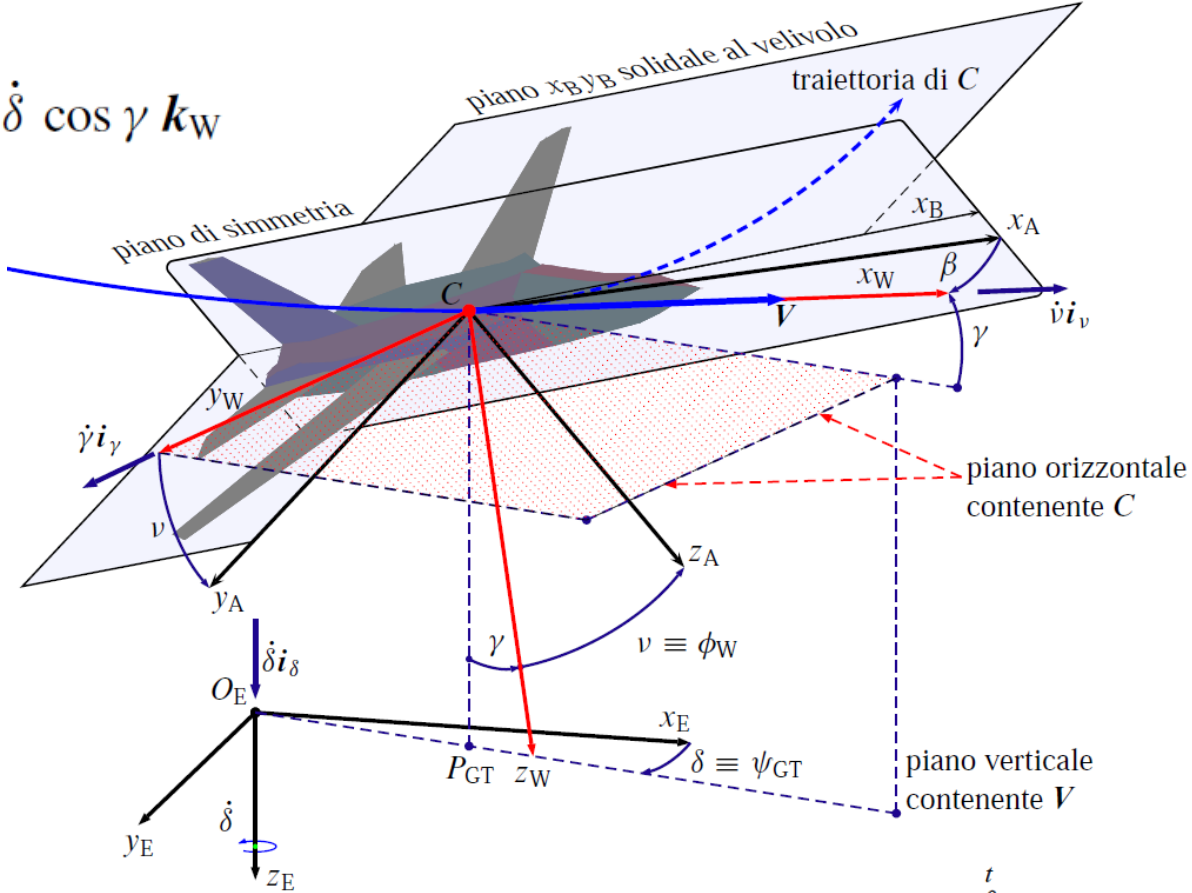
Figura 1.16 Vettore velocità angolare istantanea Ω_B e sue componenti nel riferimento degli assi velivolo. La retta individuata dagli angoli ξ_x , ξ_y e ξ_z all'istante generico t rappresenta l'asse mobile intorno a cui il velivolo compie una rotazione rigida istantanea di entità $\Omega_B dt$.

Evoluzione

$$\mathbf{E} = -\dot{\delta} \sin \gamma \mathbf{i}_W + \dot{\gamma} \mathbf{j}_W + \dot{\delta} \cos \gamma \mathbf{k}_W$$

$$\boldsymbol{\Omega}_W \equiv \mathbf{E}$$

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



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

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

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

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

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

Evoluzione



Assi aerodinamici

$$\mathbf{A} = \dot{\nu} \mathbf{i}_W + \dot{\alpha} \mathbf{j}_B - \dot{\beta} \mathbf{k}_A$$

$$\boldsymbol{\Omega}_A = \mathbf{E} + \dot{\nu} \mathbf{i}_W - \dot{\beta} \mathbf{k}_A$$

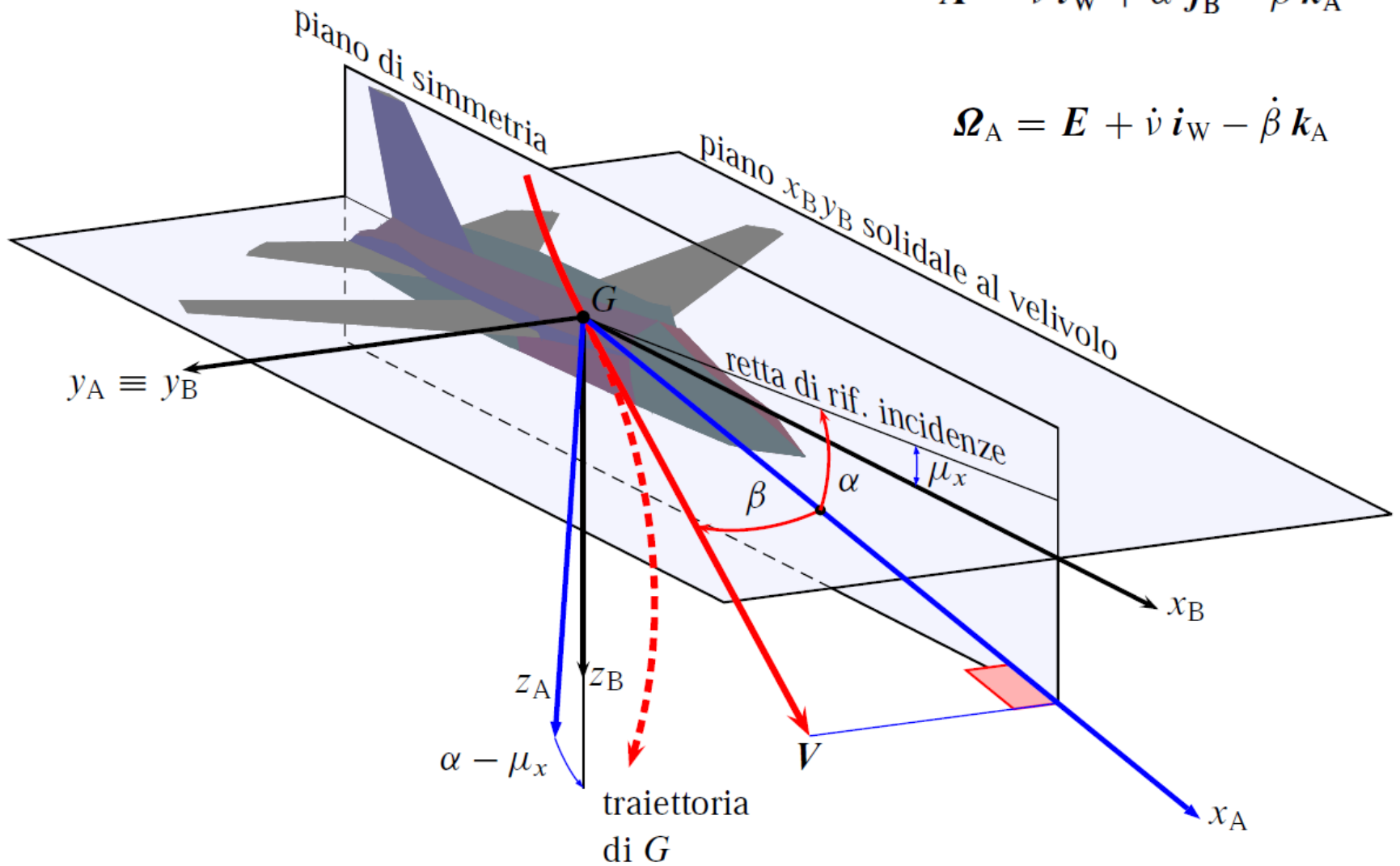


Figura 1.14 Assi aerodinamici ed assi velivolo.

Assi velivolo e angoli di Eulero

$$\Omega_B = \Omega_A + \dot{\alpha} j_B$$

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

$$\Omega_B = E + A$$

$$\Omega_B \cdot i_B = \Omega_{B,x_B} \equiv p$$

$$\Omega_B \cdot j_B = \Omega_{B,y_B} \equiv q$$

$$\Omega_B \cdot k_B = \Omega_{B,z_B} \equiv r$$

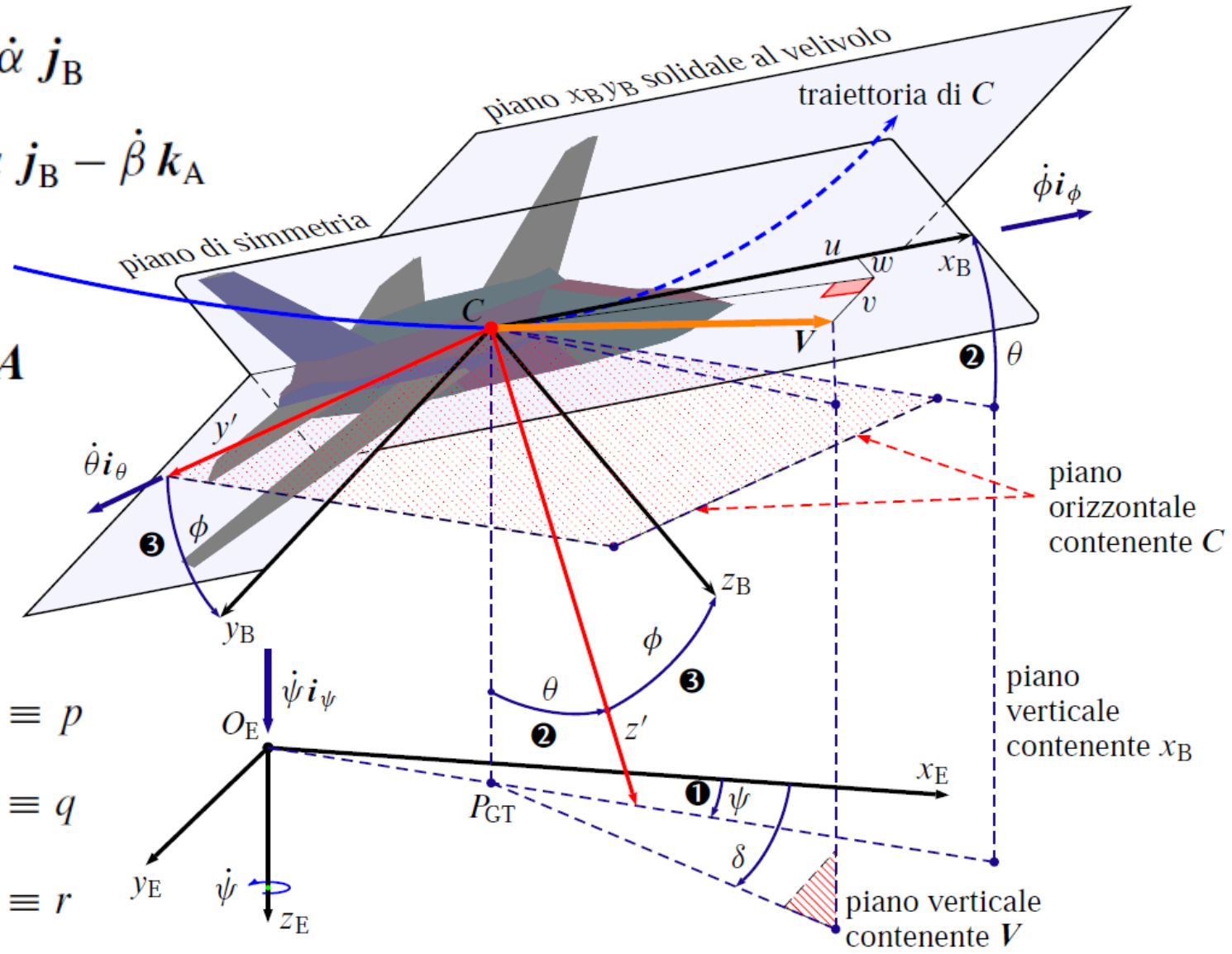


Figura 1.15 Assi velivolo ed angoli di Eulero.

(p, q, r)

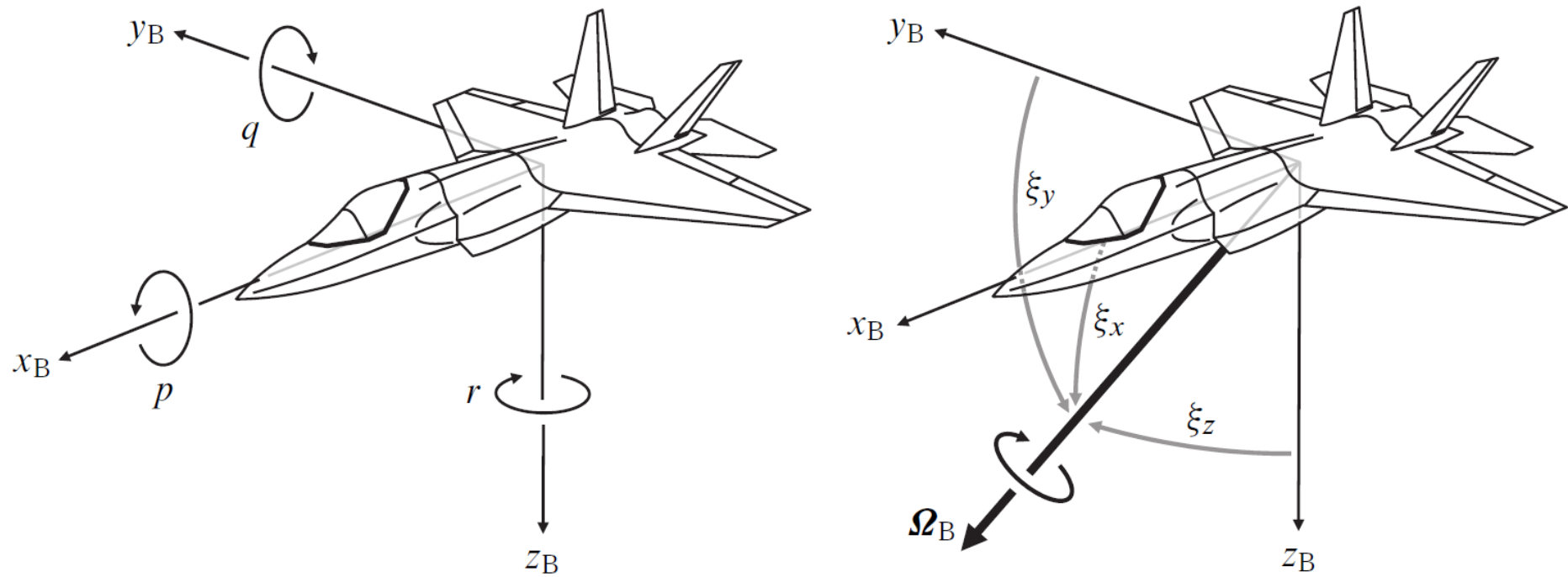


Figura 1.16 Vettore velocità angolare istantanea Ω_B e sue componenti nel riferimento degli assi velivolo. La retta individuata dagli angoli ξ_x , ξ_y e ξ_z all'istante generico t rappresenta l'asse mobile intorno a cui il velivolo compie una rotazione rigida istantanea di entità $\Omega_B dt$.

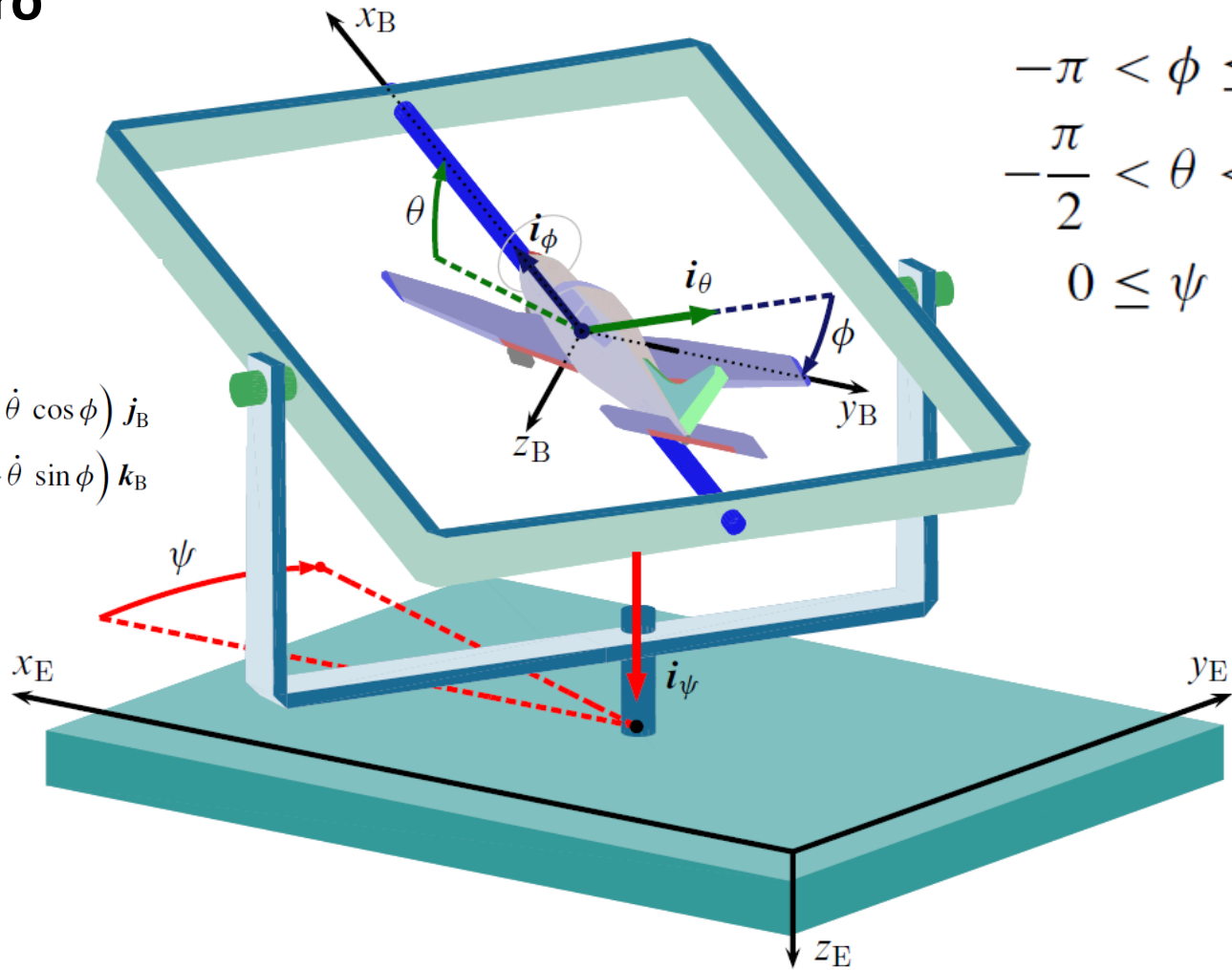
$$p = \Omega_{A,x_B} , \quad q = \Omega_{A,y_B} + \dot{\alpha} , \quad r = \Omega_{A,z_B}$$

Moto vario



Angoli di Eulero

$$\begin{aligned}\boldsymbol{\Omega}_B &= \dot{\psi} \mathbf{i}_\psi + \dot{\theta} \mathbf{i}_\theta + \dot{\phi} \mathbf{i}_\phi \\ &= (\dot{\phi} - \dot{\psi} \sin \theta) \mathbf{i}_B \\ &\quad + (\dot{\psi} \cos \theta \sin \phi + \dot{\theta} \cos \phi) \mathbf{j}_B \\ &\quad + (\dot{\psi} \cos \theta \cos \phi - \dot{\theta} \sin \phi) \mathbf{k}_B\end{aligned}$$



$$\begin{aligned}-\pi &< \phi \leq \pi \\ -\frac{\pi}{2} &< \theta < \frac{\pi}{2} \\ 0 &\leq \psi < 2\pi\end{aligned}$$

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

Angoli di Eulero

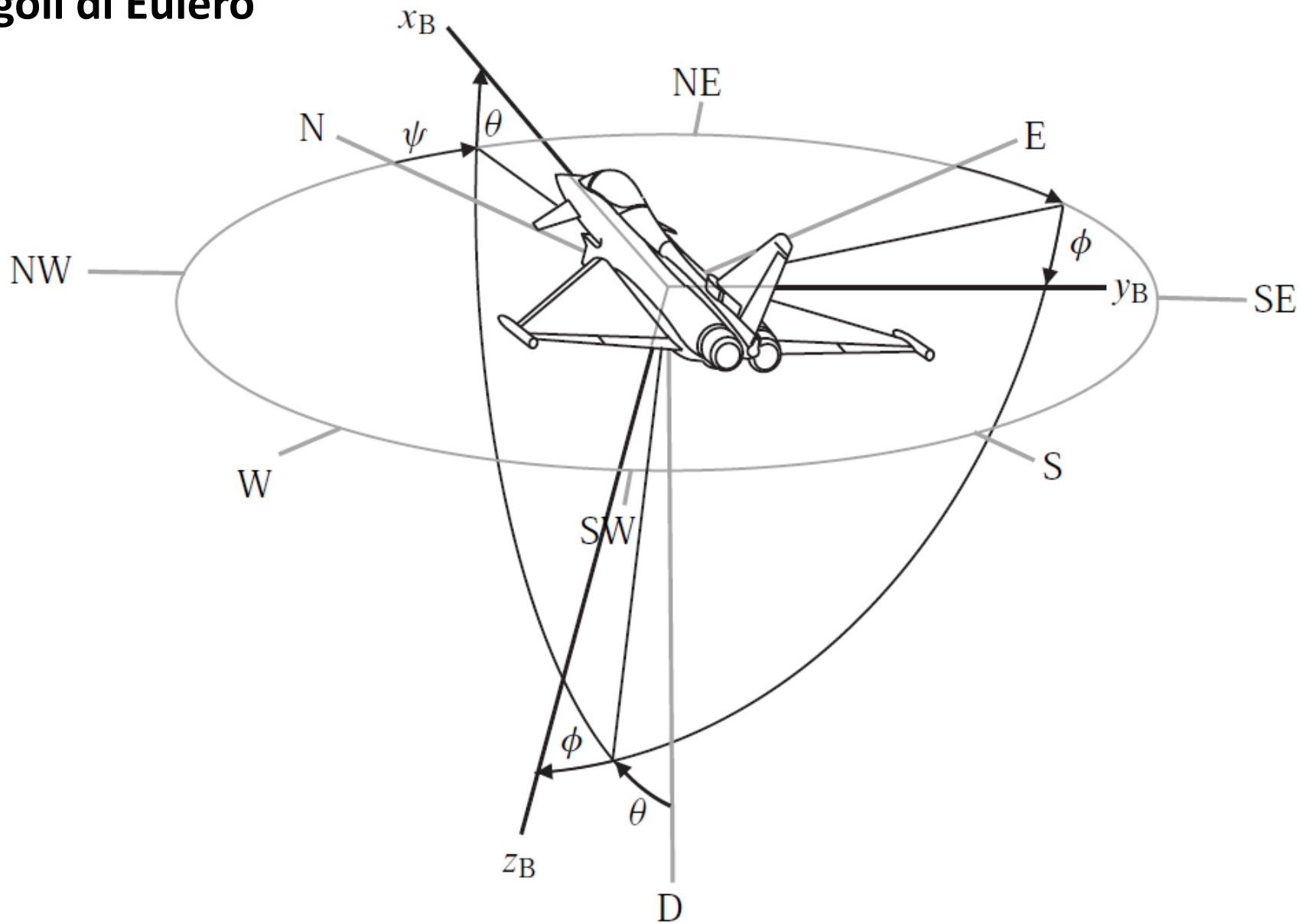


Figura 1.18 Orientamento del velivolo e significato degli angoli di Eulero rispetto alla usuale simbologia degli indicatori di bordo (*Horizontal Situation Indicator*, HSI).

Traiettoria e ground track

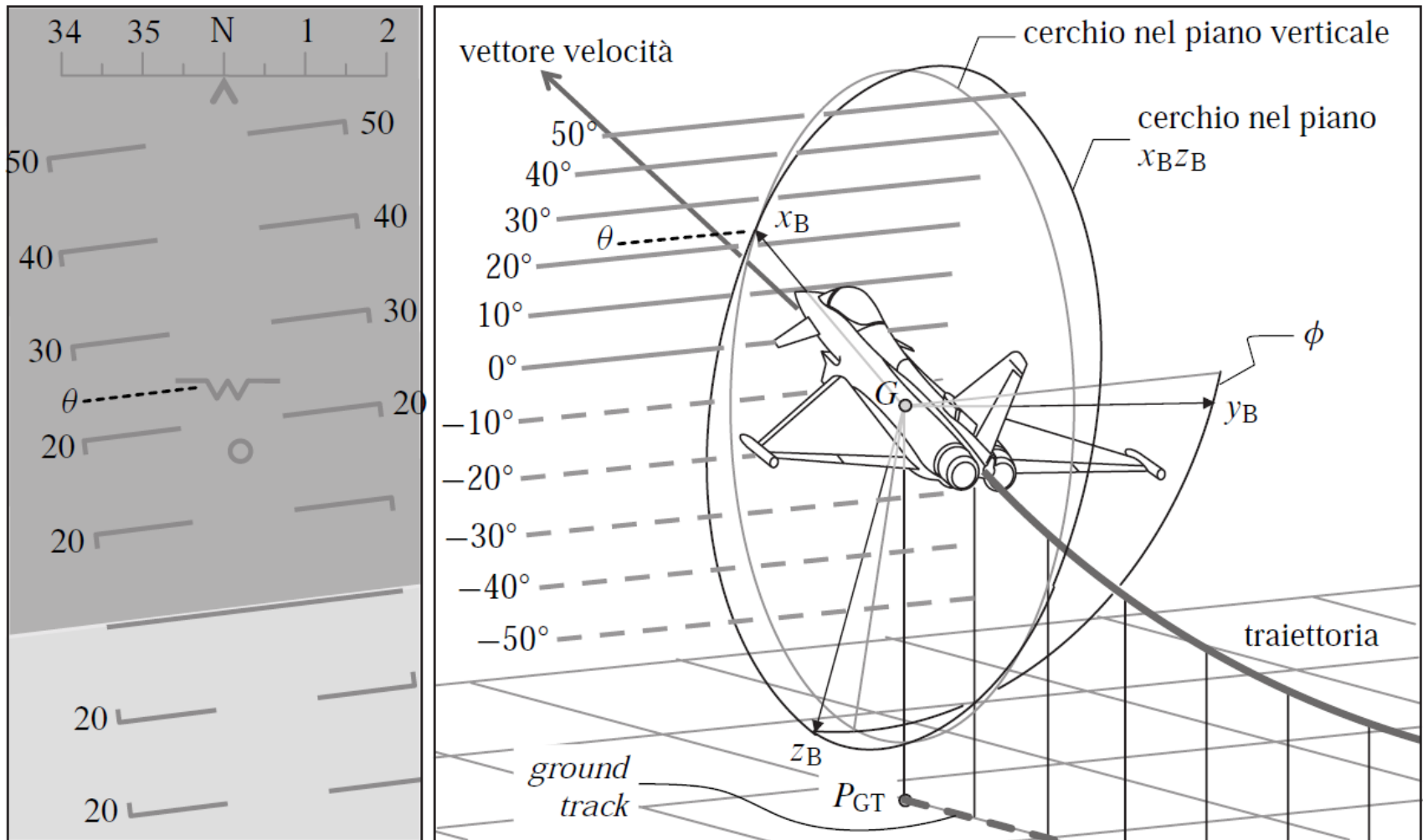


Figura 1.19 Traiettoria e *ground track*. Interpretazione dell'angolo di elevazione θ e di inclinazione laterale ϕ attraverso gli indicatori tipici di un *Head-Up-Display*.

Assi costruttivi

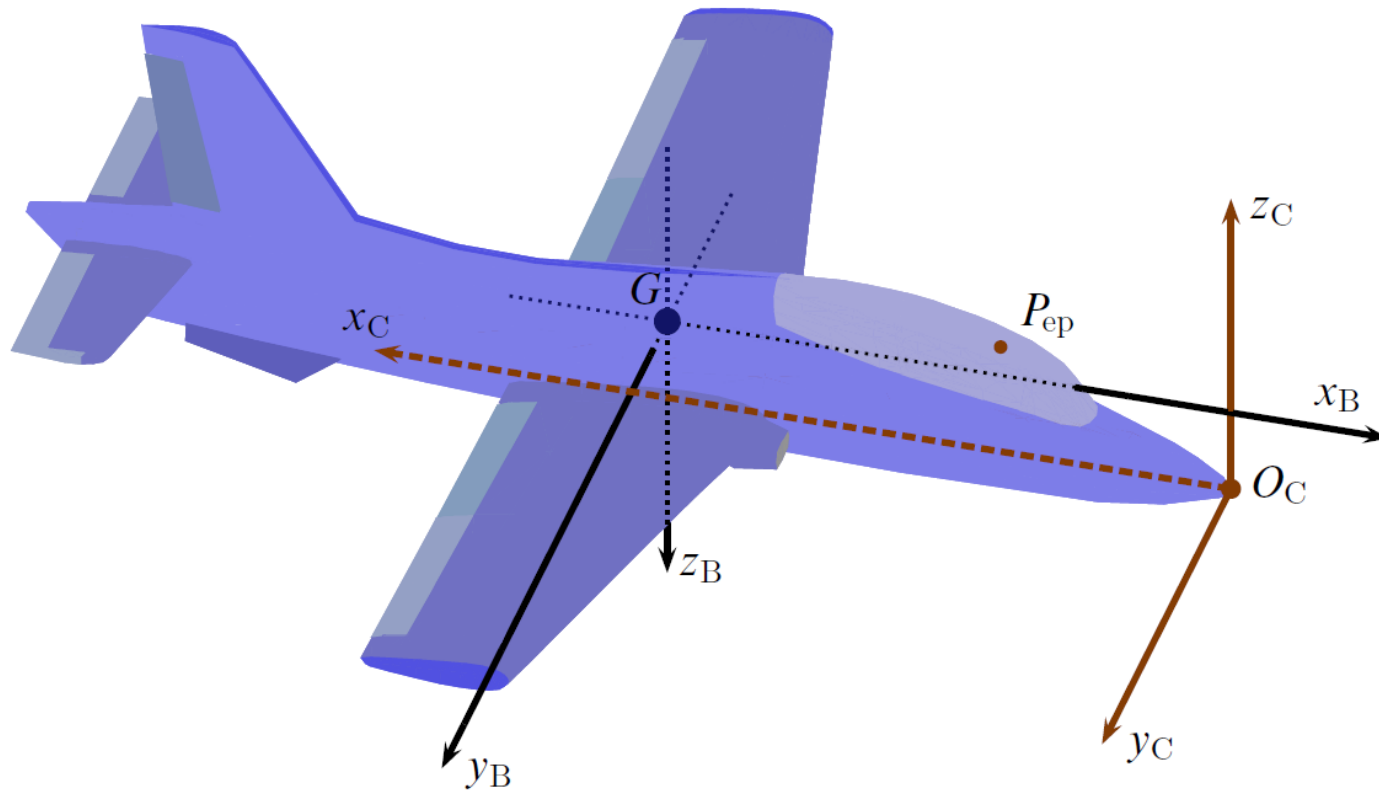


Figura 1.20 Assi velivolo ed assi costruttivi. Il punto P_{ep} è detto *pilot eye-point* ed indica la posizione della testa del pilota nel riferimento costruttivo.

Assi costruttivi

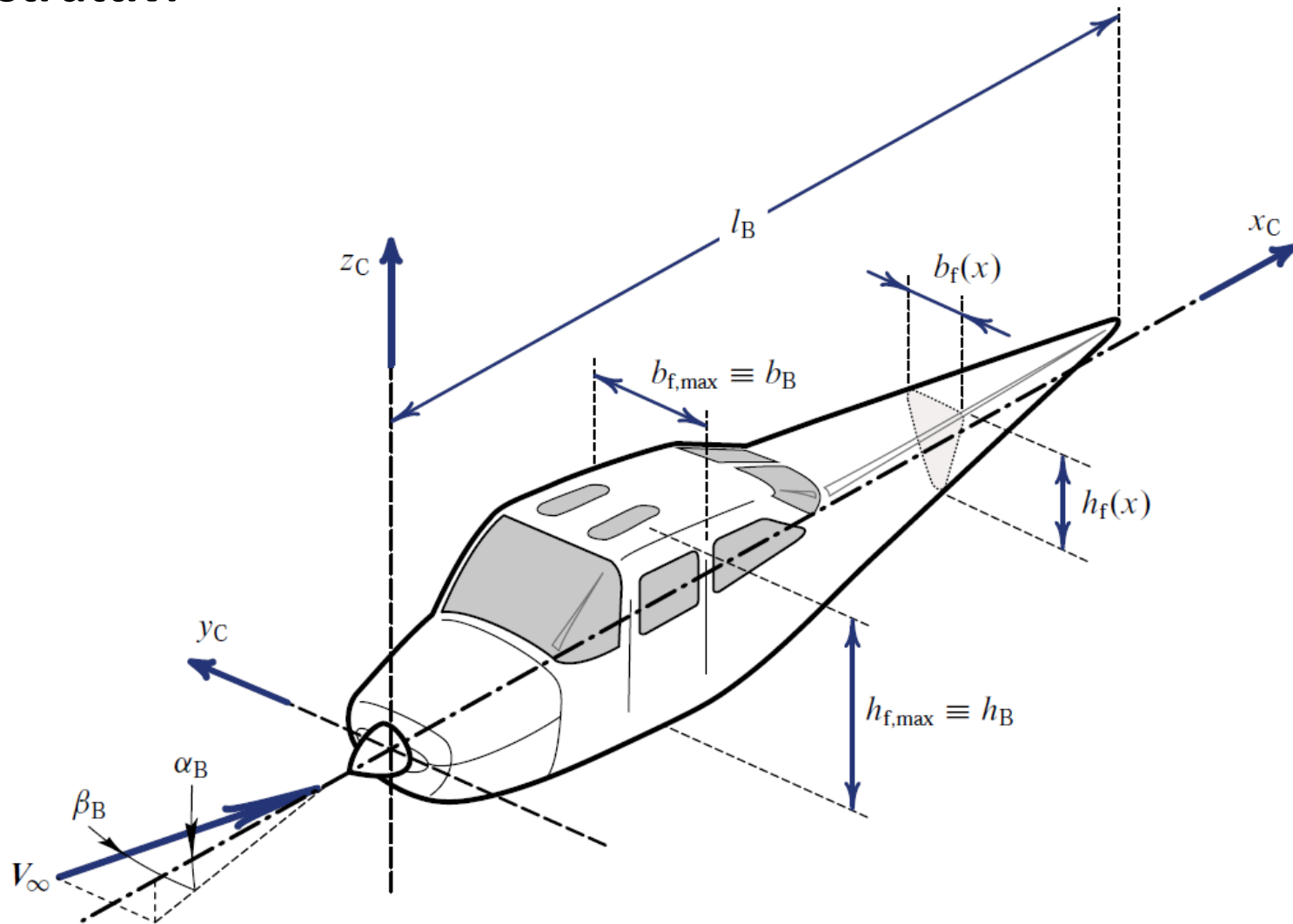


Figura 1.21 Parametri geometrici di una fusoliera.

Assi costruttivi

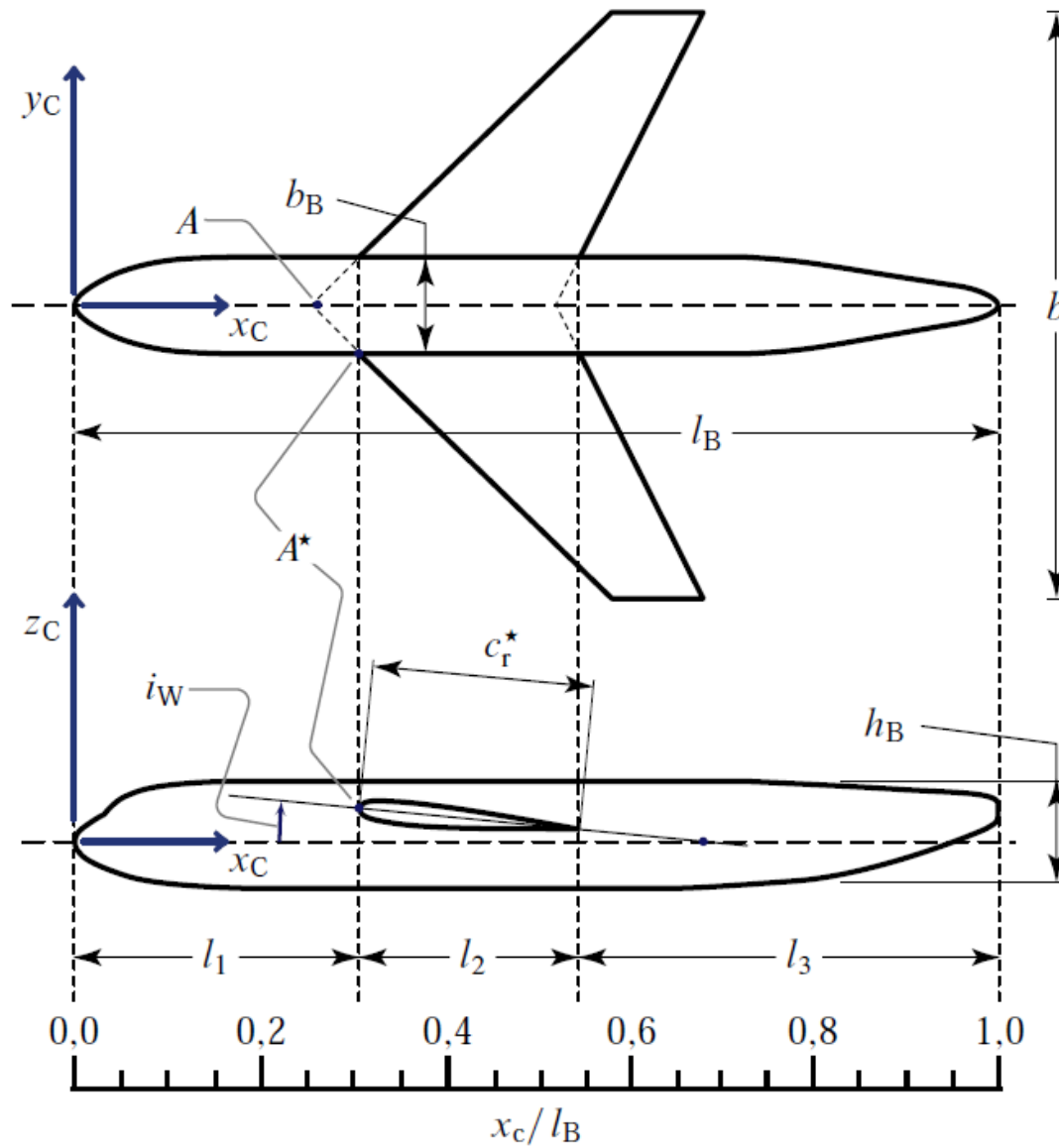


Figura 1.22 Definizioni relative alla configurazione ala-fusoliera (vista dall'alto e vista laterale).

Assi costruttivi

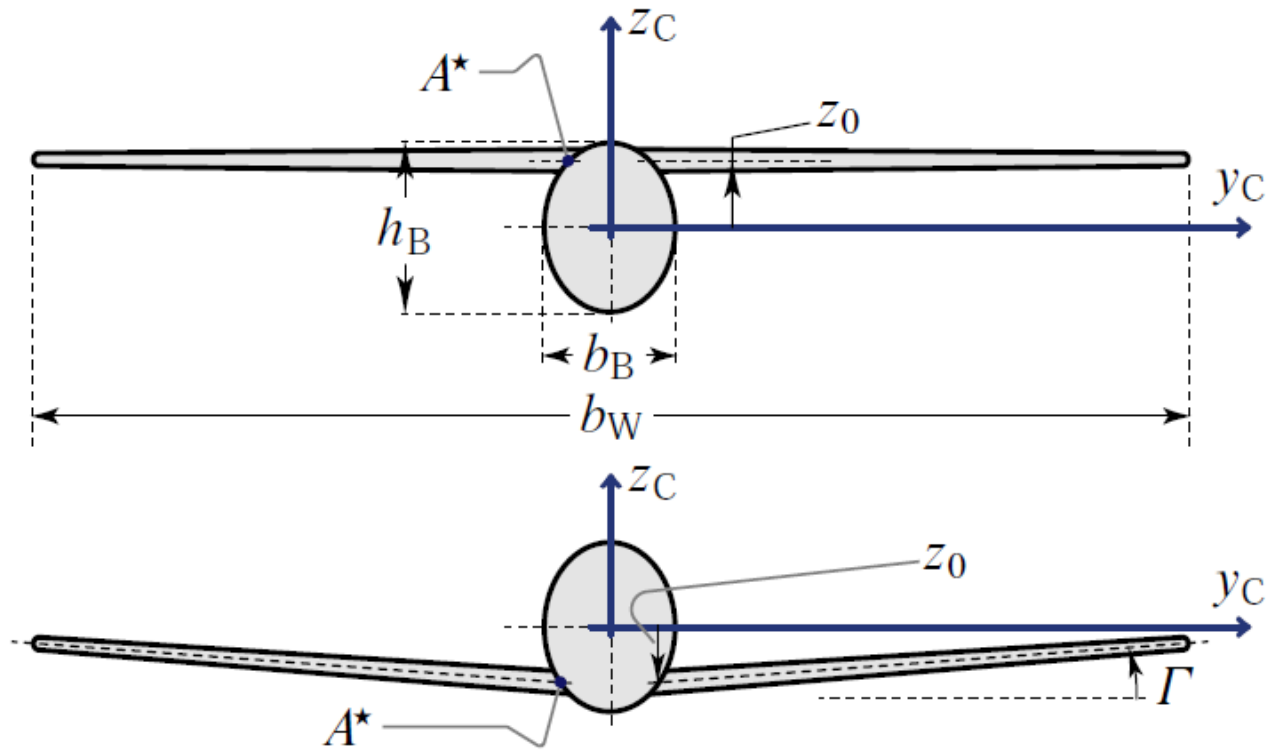


Figura 1.23 Definizioni relative alla configurazione ala-fusoliera (vista frontale).

Comandi di volo

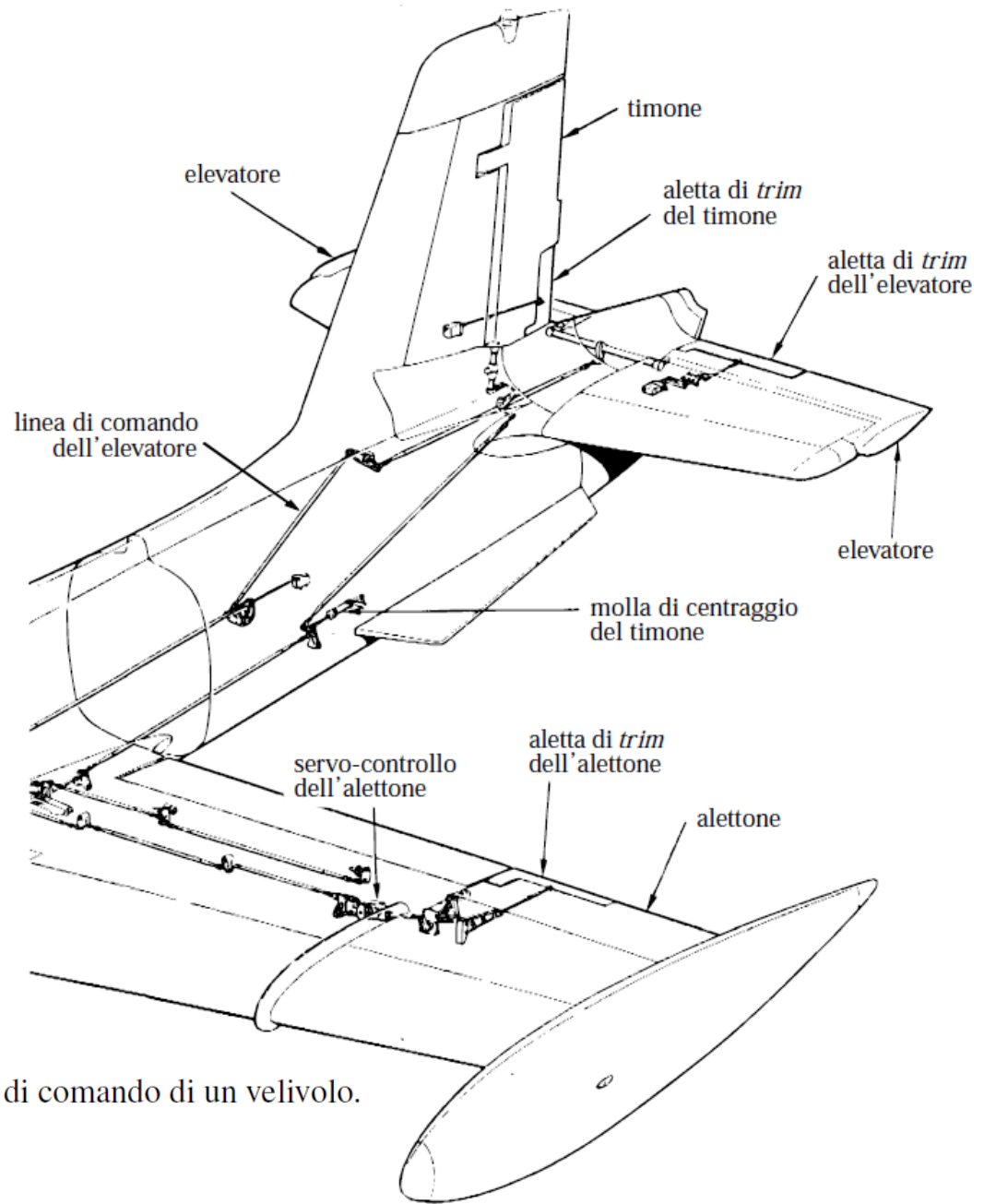
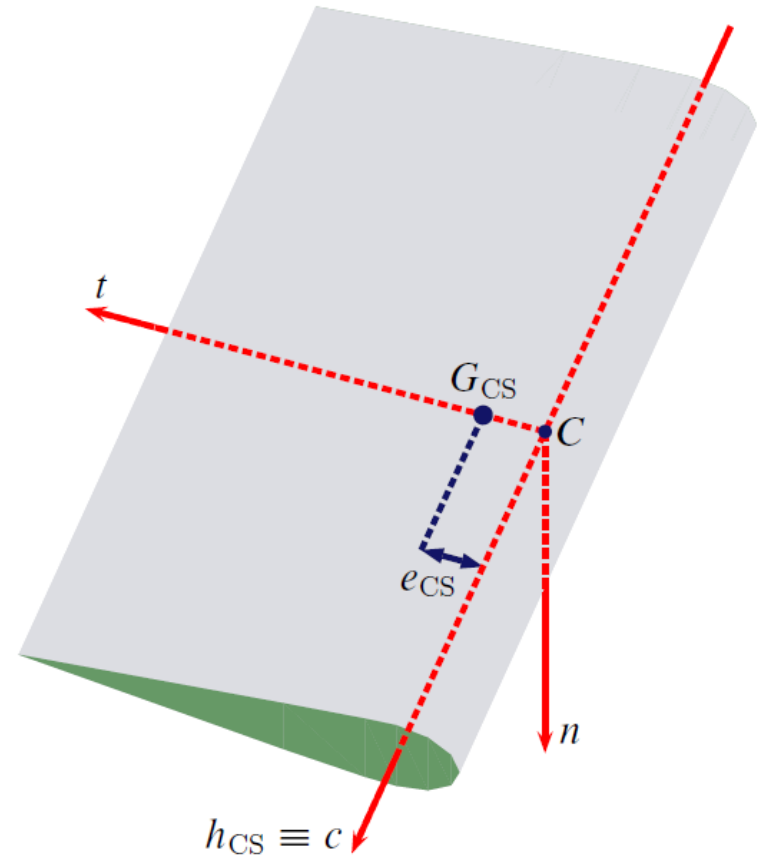


Figura 1.27 Linee di comando di un velivolo.

Assi superficie di comando

Figura 1.28 Generica terna $\mathcal{T}_{CS} = \{C, c, t, n\}$ degli assi superficie di governo. Essa si specializza, ad esempio nel caso dell'equibratore, nella terna $\mathcal{T}_{CS,e} = \{C_e, h_e, t_e, n_e\}$ e l'eccentricità diviene $e_{CS} \equiv e_e$.



Assi superficie di comando

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

