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Development of a Java-Based Framework for Aircraft Preliminary Design

Wing Aerodynamic Analysis Module,
Aircraft Longitudinal Static Stability Module

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ABSTRACT

SOMMARIO

Lo scopo che il presente lavoro di Tesi auspica raggiungere è quello di presentare le capacità possedute e le potenzialità future di ADOpT, un software scritto in Java che si configura come uno strumento veloce ed efficiente per il supporto nella fase di progetto preliminare di un velivolo e per la sua ottimizzazione.

Lo sviluppo di ADOpT (*Aircraft Design and Optimization Tool*) nasce all' interno del Dipartimento di Ingegneria Industriale dell' Università degli Studi di Napoli Federico II, ove è tutt' ora in fase di progresso. Il software è attualmente in grado di svolgere una parziale analisi multi-disciplinare di un velivolo i cui dati sono immessi dall' utente tramite XML o caricati in memoria. La linea guida dello sviluppo del software porta verso l' implementazione di un processo di ottimizzazione nel quale le analisi sono ciclicamente ripetute al fine di ottimizzare alcuni parametri mantenendone altri all' interno di limiti imposti.

Attualmente ADOpT è in grado di effettuare una completa stima dei pesi, valutare la posizione del baricentro, calcolare un notevole numero di parametri aerodinamici e caratteristiche di performance. La stima di ciascun parametro può essere effettuata tramite diversi metodi implementati, tra di loro confrontabili ed intercambiabili. Inoltre è prevista un' analisi di stabilità statica, prestazioni di decollo ed atterraggio e la generazione del diagramma *PayloadRange*.

ADOpT può essere utilizzato sia in modalità *batch*, ossia da riga di comando, che tramite interfaccia grafica. Tale duplice scelta consente di ottenere le migliori prestazioni sia nei processi di analisi, ove la GUI consente di avere un immediato riscontro grafico, sia nei processi di ottimizzazione.

Dunque le potenzialità di ADOpT nel mondo della ricerca od anche in quello industriale sono senza dubbio notevoli e il software gioca i suoi punti di forza in un' elevata flessibilità e una notevole rapidità di calcolo, senza dimenticare e una *user-friendly* interfaccia grafica.

Per cercare di fornire una completezza di esposizione, ma allo stesso tempo risultare un utile manuale per lo sviluppatore, l' organizzazione di questo lavoro di Tesi è quella di fornire preliminarmente, per ogni capitolo, una panoramica sulla teoria alla base dei metodi implementati seguita dalla descrizione delle classi e dei metodi relativi in Java e, infine, è riportato il codice della *Test Class* relativa per poter svolgere l' analisi. I primi capitoli, invece, rappresentano una visione globale del software con particolare attenzione alle funzionalità presenti e alle scelte effettuate.

Contents

I	Aircraft Design Overview	1
1	Aircraft Design	2
2	ADOpT applicaton overview	3
II	Development of Application	4
3	Introdtion to Java	5
4	Work Object	6
4.1	Introduction	6
4.2	Input data from .XML file	6
4.3	Default Aircraft	7
4.3.1	How is made a default Aircraft	8
4.3.2	How is made a default Wing	9
4.4	Database in JPAD	12
4.4.1	Setup database	12
4.4.2	Assign database using an Aircraft object	13
4.4.3	Assign database using a Wing object	13
4.4.4	User's guide	14
III	Functionality Overview	16
5	Lift characteristics of a wing	17
6	Drag characteristics of a wing	18
7	Downwash Estimation	19
7.1	Theoretical background	19
7.2	Java Class Architecture	21
7.2.1	Constant Downwash Gradient	22
7.2.2	Variable Downwash Gradient	22
7.3	User's Guide	22
8	Longitudinal stability of an aircraft	23
8.1	Aerodynamic Lift	23
8.1.1	Wing	23

8.1.2	Fuselage	23
8.1.3	Horizontal Tail	23
8.1.4	Complete Aircraft	24
8.2	Aerodynamic Drag	25
8.3	Pitching Moments	25
8.3.1	Wing	25
8.3.2	Fuselage	25
8.3.3	Horizontal Tail	25
8.3.4	Propulsors	25
8.3.5	Stability Calculation	25
8.4	Java Class Architecture	25
8.5	User's Guide	25
8.6	Analysis Results	25
9	Minor Works	26
Appendices		
A	Java Reference	28
A.1	Inheritance, Overriding and Polymorphism	28
A.2	Packages	28
A.3	Documentation	29
Glossary		31
Acronyms		33
List of symbols		34
Bibliography		36

Part I

Aircraft Design Overview

Chapter **1**

Aircraft Design

Chapter **2**

ADOpT applicaton overview

Part II

Development of Application

Chapter **3**

Introduction to Java

Work Object

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– Autore

4.1 Introduction

In JPAD it is possible to read an .XML file as input or generate an object whose data are written in the code. Both in the first and in the second case all needed variables are initialized with data relating the choosen aircraft. The difference between these two methos is that using an .XML file, user can to define its own aircraft having clear view about the needed data useful for the analysis.

Contrariwise in order to perform test of program functionality, to use a default aircraft is the most simple way to generate a work object.

4.2 Input data from .XML file

XML is a file extension for an *Extensible Markup Language (XML)* file format used to create common information formats and share both the format and the data on the World Wide Web, intranets, and elsewhere using standard ASCII text. It is defined “Markup Language” due to the use of tags that describes the content. XML is considered extensible because the markup symbols are unlimited and self-defining. So it is possible to use personal tag for each data. In this way to read an .XML file results relatively simple.[9]

The key concepts of an .XML File Format are the followings:

- markup symbol (tag)
- attribute
- tree structure

As mentioned, each part of the test is contained between an opening **markup symbol** and an end markup symbol that expressed the meaning of the text.

`<name>Test XML</name>`

Figure 4.1: Use of markup symbols in XML language.

In addition to tag name, the markup symbols may contain also some **attributes** that introduce more informations such as the unit of measure.

```
<tag attribute1='value' attribute2='value'> text </tag>
```

Figure 4.2: Use of attributes in XML language.

An .XML file has a tree structure where there are external knots that branch into internal knots.

In order to read an XML file it is necessary, first of all, to give the file path. The class `JPADXmlReader` opens the file and the methods of the class `MyXMLReaderUtils` reads the useful data from the XML having the tag path as input. It is possible to read data as `Amount`, namely with units of measurement or as `double`. The unit of measurement is written in the attributes of data in XML file.

Likewise it is possible to write output data on XML file using `JPADDataWriter` class. First of all it is necessary to define and build the xml tree structure. After each variable is associated to a name that is the markup symbol of the XML file.

4.3 Default Aircraft

Actually it is possible to define two different aircraft in order to test the functionality of the application: **ATR-72** and **B747-100B**.

The **ATR 72** is a twin-engine turboprop made by the French-Italian aircraft manufacturer ATR entered service in 1989. It was developed as a variant of the ATR 42 with a 4.5 m stretched fuselage. The ATR 72 was developed from the ATR 42 in order to increase the seating capacity (48 to 66 in standard configuration) by stretching the fuselage, increasing the wingspan, adding more powerful engines, and increasing fuel capacity by approximately 10 percent.[5] It has been typically employed as a regional airliner, although other roles have been performed by the type such as corporate transport, cargo aircraft and maritime patrol aircraft. [4]

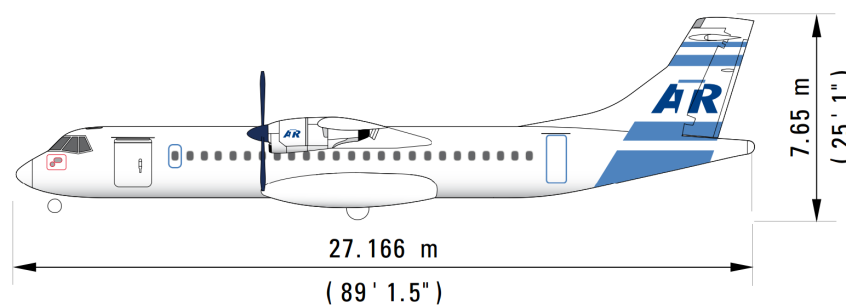


Figure 4.3: ATR 72. Side view.

The **Boeing 747-100B** is a four-engined long-range widebody commercial jet airliner and cargo aircraft produced by the American manufacturer Boeing Commercial Airplanes. It has a capacity of maximum 480 passengers in a partial double deck configuration. The Boeing 747 It is also known as Jumbo Jet. The basic B747-100 entered service with Pan American On January 15, 1970.

One of the reason to create the 747 was reductions in airfares with a consequent increase of

passenger traffic[6]. The original version of the 747 had two and a half times greater capacity than the Boeing 707, one of the common large commercial aircraft of the 1960s and it was the largest passenger carrier from 1970 until the introduction of Airbus A380.[7] The Boeing 747 had two aisle and four wing-mounted engines. The upper deck is its distinctive "hump" along the forward part of the aircraft. It provides space for a lounge or extra seating. The raised cockpit allows front loading of cargo on freight variants.

The 747-100B model was developed from the 747-100SR. This configuration had a typical 452 passengers and unlike the original 747-100, the 747-100B was offered with Pratt & Whitney JT9D-7A, General Electric CF6-50, or Rolls-Royce RB211-524 turbofan engines.

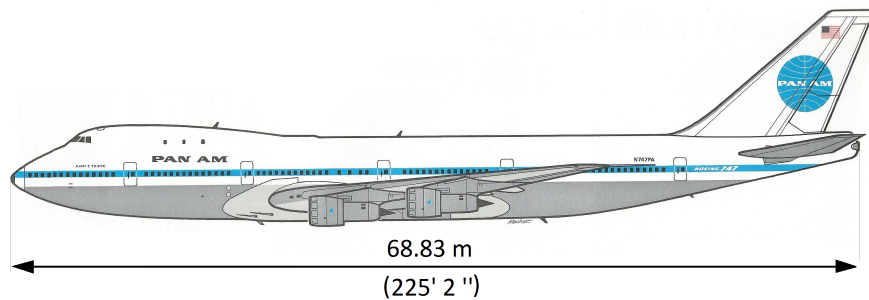


Figure 4.4: Boeing 747-100B. Side view.

4.3.1 How is made a default Aircraft

In order to define a Default Aircraft in a test class, and use it to check the functionalities of the application, it is necessary to follow some step. First of all it is necessary to initialize the working directory tree using the method `initWorkingDirectoryTree` of `MyConfiguration` class located in `JPADConfigs` package that initializes the working directory tree and fill the map of folders. This step is required in order to create the following default folders that are necessary for the right behavior of the code:

- Database directory
- Input directory
- Output directory

Using `MyConfiguration` class it's possible to point at a specific folder, like the input or output directory, with the static method `getDir`. This is a crucial step that must be execute at the beginning of every test. To set the working directory with the useful folders, it's necessary to call the function `initWorkingDirectoryTree()` at the beginning of each test. The function creates all necessary folders. Moreover the function has been overloaded and it can be even called with a variable number of arguments (`initWorkingDirectoryTree(String...str)`). These strings are the directory strings in `MyConfiguration` class. After it is possible to create an `Aircraft` object choosing between "ATR-72" or "B747-100B" using the method `createDefaultAircraft` from `Aircraft` class. This method defines a new `Aircraft` object and invokes another `Aircraft`'s methods that creates the component using default data. In the method `createDefaultAircraft` there is a calling to the builder of `Aircraft` class that initializes the objects of the classes that perform calculations. At this step all the components of the aircraft are created. It is possible also to define new airfoil for the aircraft or change some data from the existing.

Afterwards it is necessary to set the operating conditions such as the number of Mach of analysis or altitude. Each default aircraft has a set of default condition but the user could to change them.

In order to manage all the aircraft related analysis it is necessary to define an object of the class `ACAnalysisManager`. Similarly to the aircraft, exist an analysis manager also for the wing that is an object of the `LSAerodynamicAnalysis` class. The next step is to define and assign the needed databases. This will be explained in detail in the next section. Finally it is possible to do analysis.

Listing 4.1 Generation of default aircraft

```
public static void main(String[] args) {

    // -----
    // Define directory
    // -----
    MyConfiguration.initWorkingDirectoryTree();

    // -----
    // Generate default Aircraft
    // -----
    Aircraft aircraft = Aircraft.createDefaultAircraft("B747-100B");
    LiftingSurface theWing = aircraft.get_wing();

    // Default operating conditions
    OperatingConditions theConditions = new OperatingConditions();

    // -----
    // Define an ACAnalysisManager Object
    // -----
    ACAnalysisManager theAnalysis = new ACAnalysisManager(theConditions);
    theAnalysis.updateGeometry(aircraft);

    // -----
    // Define an LSAerodynamicsManager Object
    // -----
    LSAerodynamicsManager theLSAnalysis = new LSAerodynamicsManager (
        theConditions,
        theWing,
        aircraft
    );

    // -----
    // Setup database(s)
    // -----

    theLSAnalysis.setDatabaseReaders(
        new Pair(DatabaseReaderEnum.AERODYNAMIC,
            "Aerodynamic_Database_Ultimate.h5"),
        new Pair(DatabaseReaderEnum.HIGHLIFT,
            "HighLiftDatabase.h5")
    );

    // -----
    // Do analysis
    // -----
    theAnalysis.doAnalysis(aircraft,
        AnalysisTypeEnum.AERODYNAMIC);
}
```

4.3.2 How is made a default Wing

Similarly to the default aircraft it is possible to define a default wing. This is very useful if the user wants to make an analysis only on a wing. In this case it is necessary to define the origin of the **Local Reference Frame (LRF)** in **Body Reference Frame (BRF)** and the coordinates of the **Gravity Center (GC)**.



Contrary to the case of the aircraft, for an isolated wing there isn't necessary to define a fuselage in order to create a `LiftingSurface` object, but there is an overload of the builder that doesn't need a fuselage as input. In this case the exposed surface is calculated as the surface of the wing.

Listing 4.2 Generation of an isolated Wing

```
public static void main(String[] args) {

    // Assign all default folders
    MyConfiguration.initWorkingDirectoryTree();

    // -----
    // Coordinates of LRF
    // -----

    double xAw = 11.0; //meter
    double yAw = 0.0;
    double zAw = 1.6;
    double iw = 0.0;

    // -----
    // Generate default Wing
    // -----

    LiftingSurface theWing = new LiftingSurface(
        "Wing", // name
        "Data_from_AC_ATR_72_REV05.pdf",
        xAw, yAw, zAw, iw,
        ComponentEnum.WING
    );

    theWing.calculateGeometry();
    theWing.getGeometry().calculateAll();

    // -----
    // Center of Gravity
    // -----

    double xCgLocal= 1.5; // meter
    double yCgLocal= 0;
    double zCgLocal= 0;

    CenterOfGravity cg = new CenterOfGravity(
        Amount.valueOf(xCgLocal, SI.METER), // coordinates in LRF
        Amount.valueOf(yCgLocal, SI.METER),
        Amount.valueOf(zCgLocal, SI.METER),
        Amount.valueOf(xAw, SI.METER), // origin of LRF in BRF
        Amount.valueOf(yAw, SI.METER),
        Amount.valueOf(zAw, SI.METER),
        Amount.valueOf(0.0, SI.METER), // origin of BRF
        Amount.valueOf(0.0, SI.METER),
        Amount.valueOf(0.0, SI.METER)
    );

    cg.calculateCGinBRF();
    theWing.set_cg(cg);
    theWing.set_aspectRatio(6.0);

    // Default operating conditions
    OperatingConditions theOperatingConditions = new OperatingConditions();
    theOperatingConditions.set_alphaCurrent(Amount.valueOf(2.0, NonSI.DEGREE_ANGLE));

    // -----
    // Define an LSAerodynamicsManager Object
    // -----

    LSAerodynamicsManager theLSAnalysis = new LSAerodynamicsManager (
        theOperatingConditions,
        theWing
    );

    // -----
}
```

```

// Setup database(s)
// -----

theLSAnalysis.setDatabaseReaders(
    new Pair(DatabaseReaderEnum.AERODYNAMIC,
              "Aerodynamic_Database_Ultimate.h5"),
    new Pair(DatabaseReaderEnum.HIGHLIFT, "HighLiftDatabase.h5")
);

// -----
// Assign Airfoil(s) ...
// -----

// Define airfoilRoot...

// -----
// Set Airofoil(s)
// -----

List<MyAirfoil> myAirfoilList = new ArrayList<MyAirfoil>();
myAirfoilList.add(0, airfoilRoot);
myAirfoilList.add(1, airfoilKink);
myAirfoilList.add(2, airfoilTip);
theWing.set_theAirfoilsList(myAirfoilList);
theWing.updateAirfoilsGeometry();
theLSAnalysis.initializeDependentData();
}

```

4.4 Database in JPAD

In JPAD it is possible to consult external databases in .h5 format. **HDF 5** (Hierarchical Data Format Release 5) is a data file format designed by the *National Center for Supercomputing Applications* (NCSA) to assist users in the storage and manipulation of scientific data across different operating systems and machines.

To obtain the useful data in JPAD interpolating functions are used. These functions can be of one, two or three dimensions and read data from graphics that have been digitized previously. Starting from these digitalizations, databases in .h5 format are built. Reading data from databases is entrusted to methods of classes in the database package.

In order to read these databases, and obtain the useful data, it is necessary to define an object of the database reading class and associate it with the object of analysis.

This is a crucial step to read correctly the external data. In fact JPAD allows to work with an aircraft object or only with an isolated lifting surface object. Aircraft is usually composed of a fuselage, lifting surfaces, nacelle and power plant. Furthermore, Aircraft and Wing are associated with classes of calculation like `LSAerodynamicManager` or `ACAnalysisManager`. So it is necessary that these databases are also visible from these classes.

So because both in aircraft and in wing there is a lifting surface object, databases relative to wing are associated to `LSAerodynamicManager`.

4.4.1 Setup database

Here the database path it's created and associated to object that interpolates the required data from the .h5 file using a `MyInterpolatingFunction` object. After this it's possible to access the double value of the interpolating function using the `standaloneutils` method called `value`.

Now the procedure to assign the database is different if is used an Aircraft object or a Wing object.

4.4.2 Assign database using an Aircraft object

In order to assign correctly the database and associate it to all analysis management is necessary to practise the following order.

1. Define an Aircraft Object.
This command associates to Aircraft an object that defines the aerodynamic. From the wing it is possible to obtain the Wing, that is a `LiftingSurface` object.
2. Define an `ACAnalysisManager` object.
All the aircraft computations are managed by this class.
3. Define an `LSAerodynamicManager` object.
All the lifting surfaces computations are managed by this class.
4. Associate database to `LSAerodynamicManager`.
5. Eventually do analysis.

4.4.3 Assign database using a Wing object

Using a Wing object it isn't necessary to define a manager for Aircraft aerodynamic analysis. So the step to follow are the same of aircraft starting from the third.

1. Define an Wing Object.
2. Define an `LSAerodynamicManager` object.
3. Associate database to `LSAerodynamicManager`.

The definition of a isolated Wing is explained in the relative section.

Listing 4.3 Assign database using an Aircraft object

```
// -----  
// Setup database(s)  
// -----  
  
theLSAnalysis.setDatabaseReaders(  
    new Pair(DatabaseReaderEnum.AERODYNAMIC,  
              "Aerodynamic_Database_Ultimate.h5"),  
    new Pair(DatabaseReaderEnum.HIGHLIFT,  
              "HighLiftDatabase.h5")  
);
```

The databases are assigned to `LSAerodynamic` using a method of this class. This method accept as input a variable number of `Pair` objects. Using `Pair` objects it is possible to assign, for each database, both name and type.

Listing 4.4 `setDatabaseReaders` method

```
public void setDatabaseReaders(Pair... args) {  
    String databaseFolderPath = MyConfiguration.getDir(FoldersEnum.DATABASE_DIR);  
  
    for (Pair a : args) {  
        DatabaseReaderEnum key = (DatabaseReaderEnum)a.getKey();  
        String databaseFileName = (String)a.getValue();  
    }  
}
```

```
switch (key) {  
    case AERODYNAMIC:  
        _aerodynamicDatabaseReader =  
            new AerodynamicDatabaseReader(  
                databaseFolderPath,  
                databaseFileName);  
        listDatabaseReaders.add(_aerodynamicDatabaseReader);  
        break;  
  
    case HIGHLIFT:  
        _highLiftDatabaseReader =  
            new HighLiftDatabaseReader(  
                databaseFolderPath,  
                databaseFileName);  
        listDatabaseReaders.add(_highLiftDatabaseReader);  
        break;  
}
```

4.4.4 User's guide

In order to execute some analysis in JPAD it is necessary, first of all, to define an analysis object in the Test class. The method `createDefaultAircraft` creates a new aircraft and the object that composes it. This method also populates the data of aircraft with default value corresponding to ATR-72 or Boieng 747_100B. Moreover the method `createDefaultAircraft` calls another method in Aircraft class: `initialize` that initializes the objects of the classes that perform calculations.

The purpose of this structure is to have only a way to assign the databases at an aircraft. Inasmuch as the wing is always present, the chosen strategy is to assign the database to the aerodynamic manager of the wing.

In order to bring to use the database also for the aircraft calculation, it is assigned at the aerodynamic manager of the aircraft in the method called `doAnalysis`.

At the same time `LSAerodynamicManager` sets itself as aerodynamic in the wing object. So it is possible to call the database using equally the following codes:

- `theWingObject.getAerodynamics.get_Database;`
- `theAircraftObject.get_theAerodynamic.get_Database;`
- `theLSManagerObject.get_Database;`
- `theACManagerObject.get_Database;`

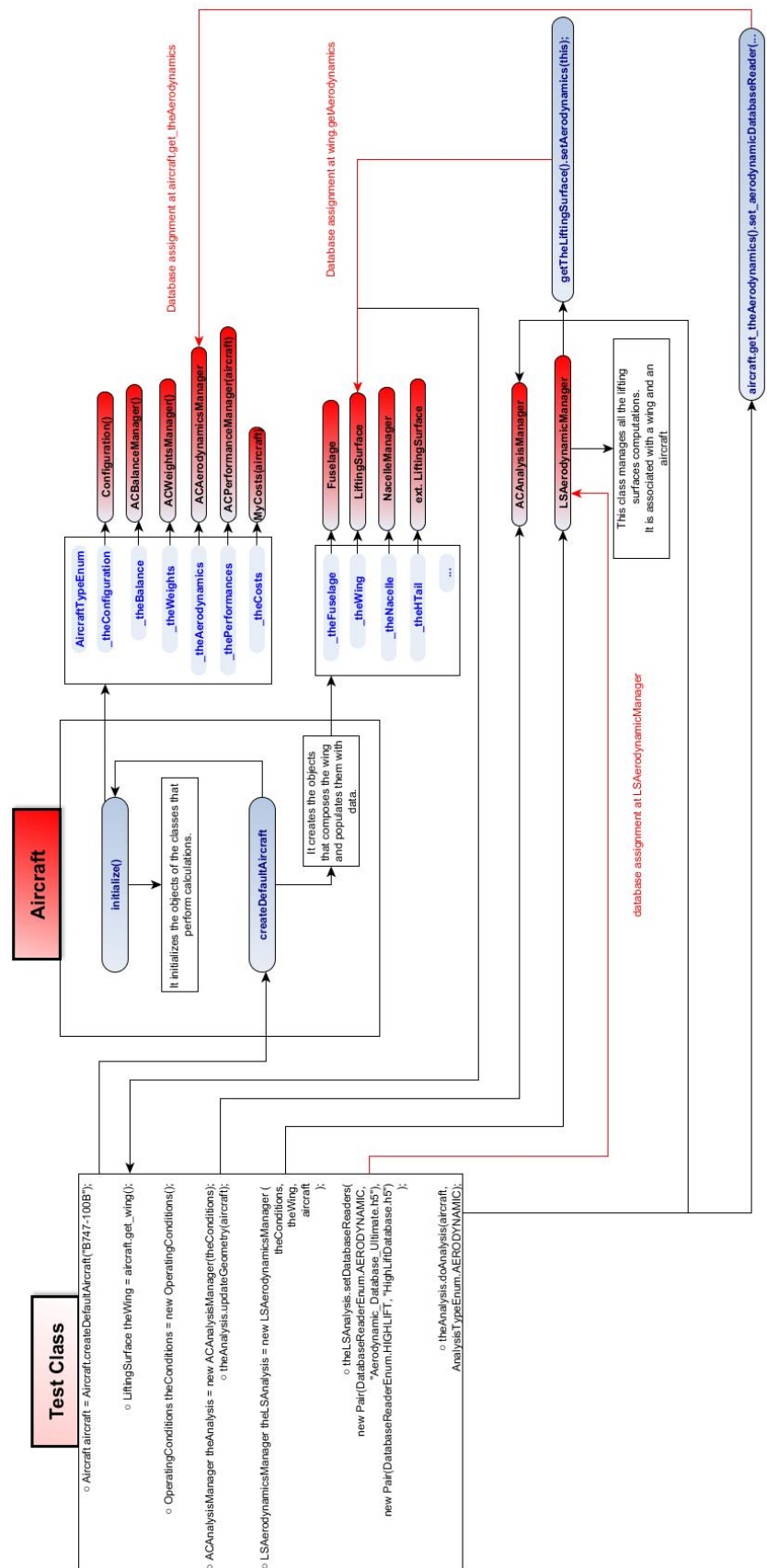


Figure 4.6: Flow chart of database assignment.

Part III

Functionality Overview

Chapter 5

Lift characteristics of a wing

Chapter 6

Drag characteristics of a wing

Downwash Estimation

In order to evaluate the characteristics of longitudinal stability of an aircraft it's necessary to assess the flow direction aft of the wing. The contribution of horizontal tail surface to the airplane equilibrium and stability, in fact, depends seriously on the flow direction. The purpose of this chapter is to introduce and evaluate the downwash gradient due from the wing's vortex system, considering a dependence of the downwash angle from the absolute angle of attack.

7.1 Theoretical background

Due to the finite extension of the wing the lift distribution in span is not uniform. For this reason the difference of pressure between upper and lower surfaces generates a movement of air around the wingtips. The tendency is for particles of air to move from the region of high pressure around the wing tip to the region of low pressure (for positive lift from the lower wing surface to the upper surface). This made the wing's vortex system that consisting of the bound vortex, located at the wing quarter chord and a vortex sheet which rolling up, at the wing tip, in two trailing vortex.[50] [63]

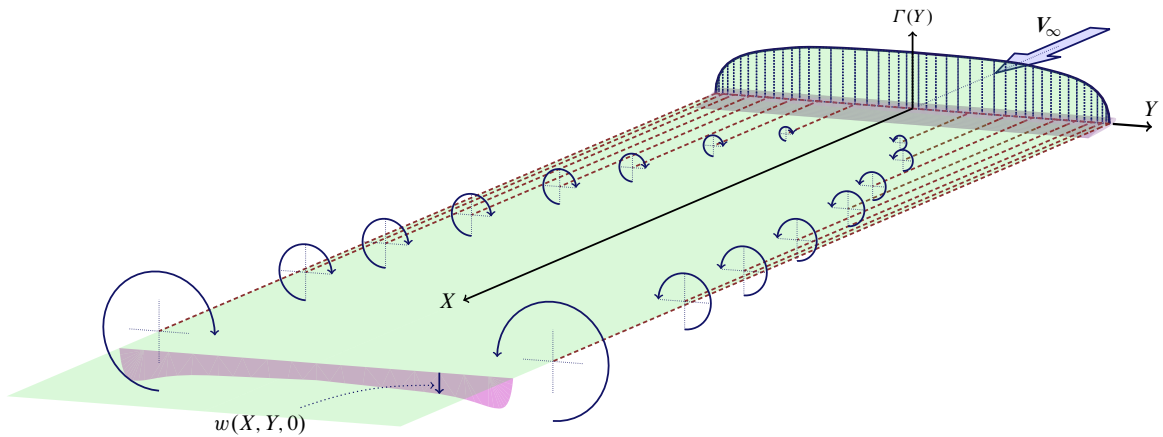


Figure 7.1: The wing vortex sheet.

The main effect of this vortex system is to deflect the airflow behind the wing downward relative to the direction of freestream flow. This angle of deviation is known as *Downwash Angle* ϵ . This phenomenon occurs for every lifting surface, but in subsonic flow a lifting surface also affects the flow forward of itself. In this region the vortex creates an itshape

upwash, that is an upward flow deflection.

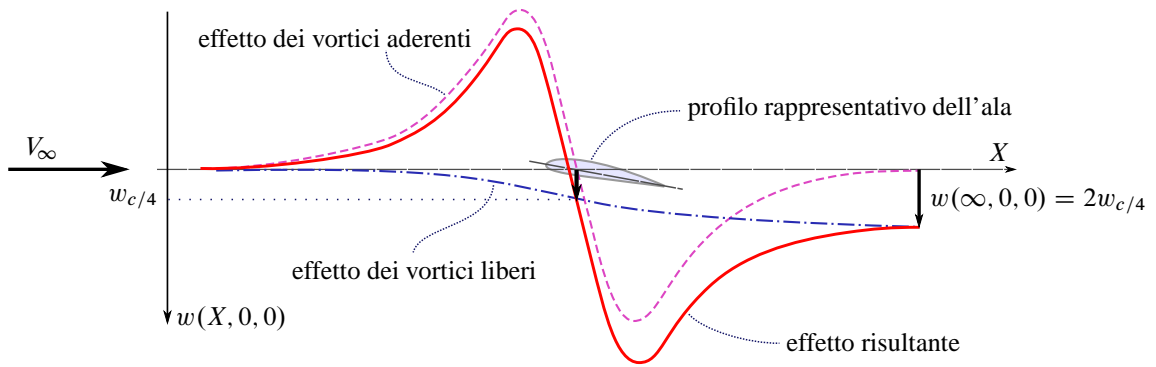


Figure 7.2: Upwash and Downwash in a finite wing.

As consequence of the downwash behind the wing, the local angle of attack on the horizontal tail is reduced by ϵ . In order to evaluate the downwash direction behind the wing, an other important parameter is the change in downwash angle with angle of attack, that is the *Downwash Gradient* $\frac{d\epsilon}{d\alpha}$.

This parameter depends principally on the location of the horizontal tail with respect to the wing and the vortex plane. As first approximation this value could be considered constant in α , but more accurately it's possible to evaluate this dependence considering the reference variable for the calculation of the distances. Both if the vertical distance is considered as constant and it is considered variable with α , starting from the downwash gradient, the downwash angle is :

$$\epsilon = \frac{d\epsilon}{d\alpha_w} (\alpha_w - \alpha_{0_w}) \quad (7.1)$$

In order to evaluate the downwash gradient it refers to fig. 7.3, where " $r \frac{b}{2}$ " is the distance between the aerodynamic center of wing and the aerodynamic center of the horizontal tail. This is a geometric and fixed distance. Conversely, in order to have a greater accuracy it's possible to consider the distance " $m \frac{b}{2}$ " variable with the angle of attack. Properly this is the distance between the horizontal tail and the vortex shed plane, but it's possible to approximate it with the distance between the horizontal tail and the wing root chord.[61]

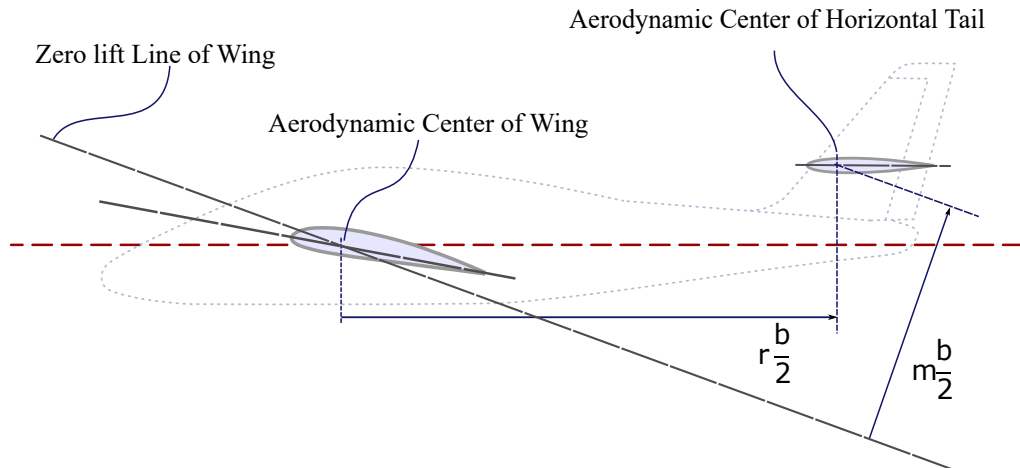


Figure 7.3: Dimensions for determination of Downwash Gradient.

$$\frac{d\epsilon}{d\alpha} = \frac{K_{\epsilon\Lambda}}{K_{\epsilon\Lambda=0}} \left(\frac{r}{r^2 + m_{tv}^2} \frac{0.4876}{\sqrt{r^2 + 0.6319 + m_{tv}^2}} + \left[1 + \left(\frac{r^2}{r^2 + 0.7915 + 5.0734m_{tv}^2} \right)^{0.3113} \right] \left\{ 1 - \sqrt{\frac{m_{tv}^2}{1 + m_{tv}^2}} \right\} \right) \frac{C_{L\alpha w}}{\pi AR} \quad (7.2)$$

Where the two K_{ϵ} terms accounting for the wing sweep angle effect are defined as follow (where Λ expressed in radians):

$$K_{\epsilon\Lambda} = \frac{0.1124 + 0.1265\Lambda + 0.1766\Lambda^2}{r^2} + \frac{0.1024}{r} + 2 \quad (7.3)$$

$$K_{\epsilon\Lambda=0} = \frac{0.1124}{r^2} + \frac{0.1024}{r} + 2 \quad (7.4)$$

7.2 Java Class Architecture

In order to simplify the calculation of downwash, as mentioned, it's possible to assume the downwash gradient constant with the angle of attack. In this case the reference line to calculate the distance along z axis is the plane from the wing root chord or else the zero-lift line of the wing.

To obtain a more accurate analysis it's possible to consider the variation in alpha of the downwash gradient. So the reference line of wing it's not constant, but is the vortex shed plane. The location of this plane depend from the value of downwash, but this location is itself necessary to evaluate the downwash. So it's necessary an iterative process in which the position of the vortex reference line at alpha is calculated from the value of downwash gradient at previous step.

In this process the reference angle of attack is the absolute angle α_a , that is the angle between the flow direction and the zero lift line of the wing. This choice is necessary because for $\alpha_a = 0$ it's possible to assume the downwash zero, but the downwash gradient is not null. In view of stability, however, the reference angle of attack is the α_B . The relation between these angles is in the fig 7.4.

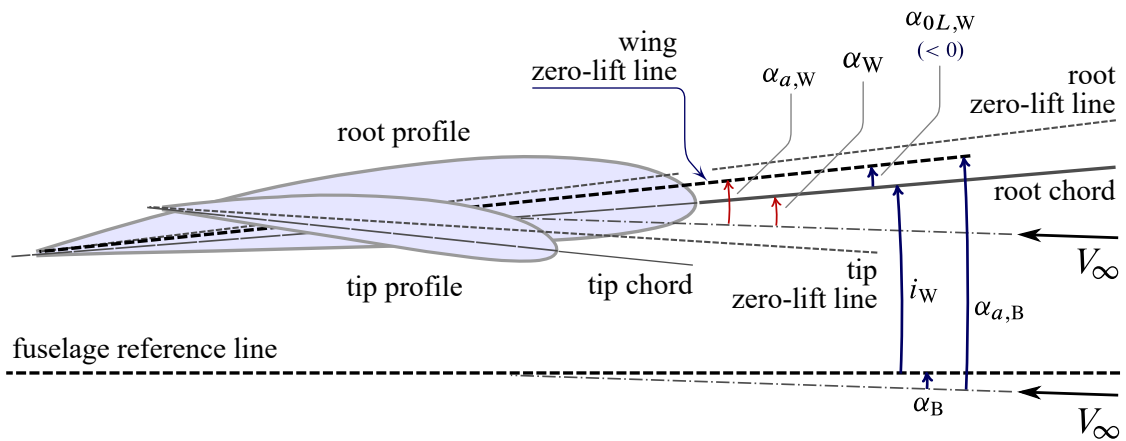


Figure 7.4: Definition of wing angles.

The downwash angle is calculated by a class named `DownwashCalculator`. The builder of this class defines and assigns all the geometrical variables, necessary to implement the calculation. The `DownwashCalculator` class has seven methods and some overloads. The methods are explained in the table 7.1. The methods will be explained more in detail below.

<code>calculateDownwashGradientConstantDelft</code>	This method calculates the downwash gradient considering the vertical distance geometrical and constant
<code>calculateDownwashNonLinearDelft</code>	This method calculates the downwash considering a non constant downwash gradient.
<code>getDownwashAtAlphaBody</code>	This method returns the value of downwash angle, interpolating data filled before.
<code>calculateZDistanceZeroLift</code>	This method calculates the distance between the aerodynamic centre of horizontal tail and the zero lift line of the wing.
Plot Methods ...	Using these methods it's possible to plot the downwash angle, the downwash gradient and the distance in function of α_B

Table 7.1: Methods of `DownwashCalculator` class.

7.2.1 Constant Downwash Gradient

In order to evaluate the downwash angle case of constant downwash gradient it's necessary only to use the method `calculateDownwashGradientConstantDelft`. This method has the downwash gradient as output. To obtain the angle of downwash it simply need to multiply the output value and the absolute angle of attack.

7.2.2 Variable Downwash Gradient

7.3 User's Guide

Longitudinal stability of an aircraft

8.1 Aerodynamic Lift

8.1.1 Wing

8.1.2 Fuselage

8.1.3 Horizontal Tail

Elevator index of effectiveness

In order to evaluate the contribution to the longitudinal stability of horizontal tail it's necessary to consider the deflection of the elevator.

The variation of zero lift angle is not constant with the angle of deflection. So it's necessary to evaluate the tau factor which is defined as follows:

$$\tau_e = \frac{d\alpha_{0l}}{d\delta_e} \quad (8.1)$$

Introducing this parameter the lift coefficient of the horizontal tail can be rated as follows:

$$C_{L_H} = C_{L_0} + C_{L_{\alpha_H}} \alpha_H + C_{L_{\alpha_H}} \tau_e \delta_e \quad (8.2)$$

Considering a symmetrical horizontal tail, the term C_{L_0} is zero, so it's possible to express the lift coefficient in the following form:

$$C_{L_H} = C_{L_{\alpha_H}} (\alpha_H + \tau_e \delta_e) \quad (8.3)$$

In general the value of τ is constant until about 15 deg; after this value, due to the flow separation, the effectiveness of elevator decrease and consequently the product $\tau_e \delta_e$ that appears in the equation of lift coefficient.

The evaluation of tau is made by reading of external database, considering the following graphs.

$$\tau = \alpha_\delta \eta_\delta = \frac{\alpha_{\delta_{cL}}}{\alpha_{\delta_{cI}}} \alpha_{\delta_{cI}} \eta_\delta \quad (8.4)$$

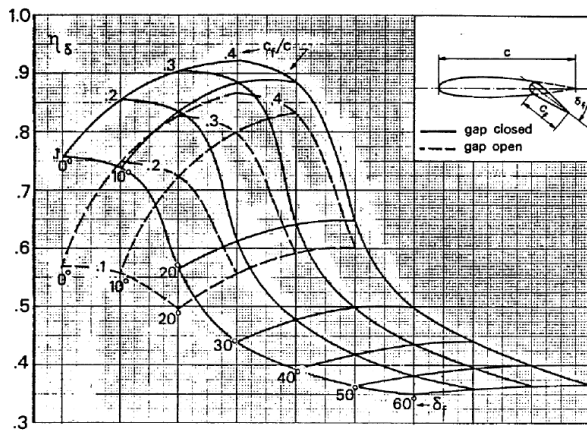
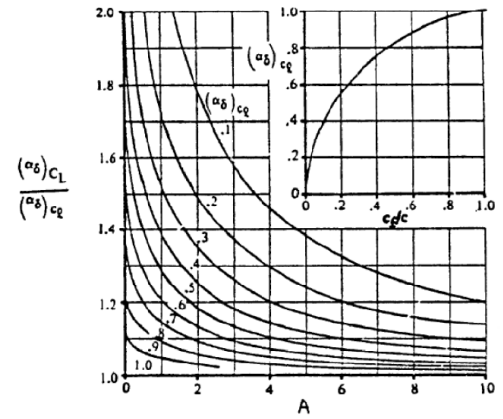


Figure 8.1: 2D efficiency correction for elevator.

Figure 8.2: $\frac{d\alpha_{0l}}{d\delta_e}$ 2D and 3D correction.

8.1.4 Complete Aircraft

In order to evaluate the lift coefficient of the entire airplane it's possible to consider it as consisting of the following parts[56]:

- wing and fuselage
- horizontal Tail
- canard

It's important to consider the effectiveness angles of attack in which the surfaces work. This is made considering the angles of incidence of the lifting surfaces and the downwash angle aft of the wing. An horizontal tail and a canard may be equipped with a trailing edge control surface. So in order to evaluate these contributes it's important to know the angle of deflection δ of these control surfaces.

The calculation of the individual contributions it's reported in the relevant sections. In this section will be shown the method to evaluate the aircraft lift coefficient, known the single contributes.

For an aircraft with no cadard, the formula is the following:

$$C_L = C_{L_{wb}} + \frac{S_t}{S_w} \eta_t C_{L_t} \quad (8.5)$$

Where η_t is the ratio of dynamic pressure. In fact the dynamic pressure seen by horizontal tail differ from the free stream dynamic pressure due to two main reasons: the combination wing-fuselage and the presence of the propeller. The dynamic pressure of the tail depends on the location of the tail. If the tail is in the wake of the wing-body, the local dynamic pressure will be less than the freestream because the flow gradually loses its kinetic energy. While if the tail is in the slipstream of propeller, the local dynamic pressure may increase due to the power absorbed by the propeller.

8.2 Aerodynamic Drag

8.3 Pitching Moments

8.3.1 Wing

8.3.2 Fuselage

8.3.3 Horizontal Tail

8.3.4 Propulsors

8.3.5 Stability Calculation

8.4 Java Class Architecture

8.5 User's Guide

8.6 Analysis Results

Chapter 9

Minor Works

Appendices

Java Reference

A.1 Inheritance, Overriding and Polymorphism

An extensive usage of inheritance, overriding and polymorphism has been made throughout the application.

Java inheritance can be defined as the process where one object acquires the properties of another. With the use of inheritance the information is made manageable in a hierarchical order. Inheritance has been used several times to define superclass-subclass relationship in order to ease the management of the instances of the subclasses and to group together a set of properties that each subclass must have. Some of the methods defined in the superclass are overridden by the subclasses to execute the proper action accordingly to the run-time object type.

Polymorphism is the ability of an object to take on many forms. The most common use of polymorphism in OOP occurs when a parent class reference is used to refer to a child class object. Any Java object that can pass more than one IS-A test is considered to be polymorphic. In Java, all Java objects are polymorphic since any object will pass the IS-A test for their own type and for the class Object. Polymorphism has been exploited in the design of methods which had to perform an action that could be valid for more than one object type. In such a case, the method signature contains a parameter which is of the superclass type; when invoking the method elsewhere in the application with a subclass instance as an argument at compile time, the compiler uses the method in the superclass to validate the statement in the "client" method. At run time, however, the JVM invokes the method which is defined in the subclass which overrides the superclass method. This behaviour is referred to as virtual method invocation, and the methods are referred to as virtual methods.

In this way it was possible to define a single method which was suitable for several objects types instead of defining a different method for each component or using the instanceof operator.

A.2 Packages

A Java package is a mechanism for organizing Java classes into namespaces, providing modular programming. Java packages can be stored in compressed files called JAR files, allowing classes to be downloaded faster as groups rather than individually. Programmers also typically use packages to organize classes belonging to the same category or providing similar functionality.

A package provides a unique namespace for the types it contains. In general, a namespace is a container for a set of identifiers (also known as symbols, names). Namespaces provide a level of direction to specific identifiers, thus making it possible to distinguish between identifiers with the same exact name. For example, a surname could be thought of as a namespace that makes it possible to distinguish people who have the same given name. In computer programming, namespaces are typically employed for the purpose of grouping symbols and identifiers around a particular functionality.

A.3 Documentation

The doc comments, which are a particular type of comments provided by Java, are automatically recognized by the most popular IDE programs; this helps the developer to quickly get an idea of the actions performed by each method, the parameter which has to be passed to it and the what it returns to the user.

Glossary

Aircraft Construction Reference Frame The reference frame which has its origin in the fuselage forwardmost point, the x-axis pointing from the nose to the tail, the y-axis from fuselage plane of symmetry to the right wing (from the pilot's point of view) and the z-axis from pilot's feet to pilot's head.

client code the code where the code in question will be effectively exploited.

Graphical User Interface In computing, a Graphical User Interface is a type of interface that allows users to interact with electronic devices through graphical icons and visual indicators such as secondary notation, as opposed to text-based interfaces, typed command labels or text navigation.

List The `java.util.List` interface is a subtype of the `java.util.Collection` interface. It represents an ordered list of objects, meaning you can access the elements of a List in a specific order, and by an index too. You can also add the same element more than once to a List.

Map The `java.util.Map` interface represents a mapping between a key and a value. The Map interface is not a subtype of the Collection interface. Therefore it behaves a bit different from the rest of the collection types.

parsing Parsing or syntactic analysis is the process of analysing a string of symbols, either in natural language or in computer languages, conforming to the rules of a formal grammar.

reflection In computer science, reflection is the ability of a computer program to examine (see type introspection) and modify the structure and behavior (specifically the values, meta-data, properties and functions) of the program at runtime.

serialization In computer science, in the context of data storage, serialization is the process of translating data structures or object state into a format that can be stored (for example, in a file or memory buffer, or transmitted across a network connection link) and reconstructed later in the same or another computer environment.

Table a collection that associates an ordered pair of keys, called a row key and a column key, with a single value. A table may be sparse, with only a small fraction of row key / column key pairs possessing a corresponding value.

Unified Modeling Language The Unified Modeling Language (UML) is a general-purpose modeling language in the field of software engineering, which is designed to provide a standard way to visualize the design of a system.

user developer the term refers to the developer which will use a method without being interested in how the method performs the required action. This is the case of a utility method: the developer is the one who writes the method, while the user developer is who uses that method to accomplish some action which requires the functionality provided by the utility method. It has to be noticed that the user developer and the developer can be the same person.

wrapper function A wrapper function is a subroutine in a software library or a computer program whose main purpose is to call a second subroutine or a system call with little or no additional computation..

Acronyms

ACRF Aircraft Construction Reference Frame.

AIAA American Institute of Aeronautics and Astronautics.

BRF Body Reference Frame.

FAA Federal Aviation Administration.

GC Gravity Center.

GNC Guidance Navigation and Control.

GUI Graphical User Interface.

JPAD Java Aircraft Design.

MAC Mean Aerodynamic Chord.

MAPE Mean Absolute Percentage Error.

MLW Maximum Landing Weight.

MSL Mean Sea Level.

MTOW Maximum Take Off Weight.

MZFW Maximum Zero Fuel Weight.

UML Unified Modeling Language.

List of symbols

- $()_{\text{H}}$ quantity related to the horizontal tail.
- $()_{\text{LG}}$ quantity related to the landing gear.
- $()_{\text{N}}$ quantity related to the nacelle.
- $()_{\text{S}}$ quantity related to systems.
- $()_{\text{V}}$ quantity related to the vertical tail.
- $()_{\text{F}}$ quantity related to the fuselage.
- $()_{\text{WF}}$ quantity related to the wing-fuselage configuration.
- D aerodynamic drag.
- CG** Center of Gravity.
- \vec{g} gravitational acceleration.
- i_{H} the angle between the horizontal tail root chord and the ACRF x-axis.
- i_{W} the angle between the wing root chord and the ACRF x-axis.
- L aerodynamic lift.
- T Thrust.
- M Mach number.
- \mathcal{AR} aspect ratio.
- c chord.
- d diameter.
- l length.
- m mass, in kg or lb.
- n_{lim} limit load factor.
- n_{ult} ultimate load factor.
- b span.

S surface.

Λ sweep.

λ taper ratio.

t thickness.

V scalar velocity.

W weight, in Newtons.

m_W wing mass.

q dynamic pressure.

Re Reynolds number (evaluated with respect to \bar{c}).

α_W angolo d'attacco riferito alla corda di radice dell'ala.

β sideslip angle.

ρ air density.

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