Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Project

Department Fahrzeugtechnik und Flugzeugbau

Preliminary Sizing of Propeller and Jet Aircraft - Extension of PreSTo and Combination with CEASIOM

Author: Marcin Lenarczyk

Examiner: Prof. Dr.-Ing. Dieter Scholz, MSME
Tutor: Dipl.-Ing. Kolja Seeckt

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Hochschule für Angewandte Wissenschaften Hamburg
Fakultät Technik und Informatik
Department Fahrzeugtechnik + Flugzeugbau
Berliner Tor 9
20099 Hamburg

In cooperation with:

Warsaw University of Technology
The Faculty of Power and Aeronautical Engineering
Warsaw
Poland

Author: Marcin Lenarczyk
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Examiner: Prof. Dr.-Ing. Dieter Scholz, MSME
Tutor: Dipl.-Ing. Kolja Seeckt

Abstract

This report introduces the process of improving and extending the HAW Hamburg's MS-Excel-based Aircraft Preliminary Sizing Tool PreSTo. The process of the combination of two previously developed preliminary sizing modules of PreSTo is presented. All aspects of the combination like layout, macros, application of the "look and feel" philosophy are described and discussed in detail. Within the scope of the project an interface to CEASIOM was set up. The report presents the new "CEASIOM input file" module and describes all already developed features of the module. Finally, the workflow of the ATR 72-600 preliminary sizing process within PreSTo with focus on the jet version of the aircraft is presented. The results of the re-design process are discussed. The determined results like masses, wing area and engine take-off thrust are of good accuracy.

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DEPARTMENT FAHRZEUGTECHNIK UND FLUGZEUGBAU

Preliminary Sizing of Propeller and Jet Aircraft – Extension of PreSTo and Combination with CEASIOM

Task for a *Master Thesis* at Warsaw University of Technology, WUT

Background

This master thesis is part of the aircraft design research project "Green Freighter" (http://GF.ProfScholz.de). Within the scope of this project the HAW Hamburg's MS Excel-based Aircraft Preliminary Sizing Tool PreSTo is being extended and applied to the initial sizing of different aircraft designs. CEASIOM (Computerised Environment for Aircraft Synthesis and Integrated Optimisation Methods) is a Matlab-based design environment for the analyses of aerodynamics, structures and flight dynamics at a very early stage during the aircraft design process.

Task

The student shall

- integrate the two existing PreSTo-modules "Preliminary sizing of large propeller driven aircraft" and "Preliminary sizing of jet aircraft" into one application and
- setup an interface to CEASIOM to, first, produce a graphical output of the new aircraft design and, second, estimate the resulting flight mechanical derivatives.

The described tasks shall be performed on the basis of a re-design and investigation of a jet and a propeller variant of the regional aircraft ATR 72.

The report has to be written according to German or international standards on report writing!

Declaration

This project is entirely my own work. Where use has been made of the work of others, it has been fully acknowledge and referenced.

2009-07-31
....
Date   Signature

Contents

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a	Speed of sound
$C_{D,0}$	Clean lift independent drag coefficient
$C_{D,p}$	Parasite drag coefficient
$\bar{c}_{f,eqv}$	Equivalent friction coefficient
$C_{L,cruise}$	Lift coefficient (cruise)
D	Drag force generated by an aircraft
d_h	Horizontal diameter of the first cross-section of the centre fuselage
d_v	Vertical diameter of the first cross-section of the centre fuselage
E	Maximum glide ratio
e	Oswald factor
g	Earth acceleration
h_{CR}	Cruise altitude
k_{app}	Approach correlation factor
L	Lift force generated by an aircraft
m_{cargo}	Cargo mass
M_{cr}	Cruise Mach number
m_F	Mission fuel fraction for standard flight
$M_{ff,CLB}$	Fuel fraction (climbe)
$M_{ff,DES}$	Fuel fraction (descent)
$M_{ff,engine}$	Fule fraction (engine start)
$M_{ff,L}$	Fuel fraction (landing)
$M_{ff,taxi}$	Fuel fraction (taxi)
$M_{ff,TO}$	Fuel fraction (take-off)
m_{mf},	Maximum fuel mass
m_{ml}	Maximum landing mass
m_{TO}	Maximum take-off mass
m_{MTO}/S_W	Wing loading
m_{mzf},	Maximum zero-fuel mass
m_{oe}	Operating empty mass
m_{OE}/m_{mTO}	Relative operating empty mass ratio
m_{pax}	Mass of a passenger
m_{mto}	Maximum take-off mass
n_{pax}	Number of passengers
R	Range
S_{wet}	Wetted area
$sin(\gamma_{missed\ app})$	Missed approach climb gradient
$sin(\gamma_{to})$	Take-off climb gradient
s_{LDA}	Landing distance available

s_{lf}	Landing distance
s_{LFL}	Landing field length
s_{to}	Take-off distance
S_W	Wing area
T,*stratosp.*	Temperature in cruise (stratosphere)
T,*troposp.*	Temperature in cruise (troposphere)
T_{TO}	Take-off thrust
$T_{TO}/(m_{MTO}*g)$	Thrust-to-weight ratio
V_{APP}	Approach speed
v_{CR}	Cruise speed
V_{mf}.	Maximum fuel volume
V_S	Stall speed

Greek symbols

γ	Flight Path Angle
μ	Bypass ratio (BPR)
ρ_f	Fuel Density
σ	Relative air density

List of Abbreviations

GF	Green Freighter
HAW	Hochschule für Angewandte Wissenschaften (University of Applied Sciences)
IFL	Institut für Flugzeugbau und Leichtbau (Technical University of Braunschweig)
FCS	Flight Control System
SimSAC	Simulating Aircraft Stability And Control Characteristics for Use in Conceptual Design
S&C	Stability and Control
GUI	Graphical User Interface
IST	International Standard Temperature
OEI	One Engine Inoperative
BPR	Baypass Ratio

List of terms and definitions

Layout

Layout is the part of graphic design that deals in the arrangement and style treatment of elements (content) on a page. Since the advent of personal computing, page layout skills have expanded to electronic media as well as print media. The electronic page is better known as a graphical user interface (GUI) when interactive elements are included. Page layout for interactive media overlaps with (and is often called) interface design. This usually includes interactive elements and multimedia in addition to text and still images. Interactivity takes page layout skills from planning attraction and eye flow to the next level of planning user experience in collaboration with software engineers and creative directors. **Wikipedia 2009a**

Look and Feel

The term "look and feel" basically refers to field such as product design, marketing, branding, etc. It describes the main features of a particular product appearance. In software design, look and feel is used with respect of a graphical user interface and comprises aspects of its design, including elements such as colours, shapes, layout, and typefaces (the *look*), as well as the behaviour of dynamic elements such as buttons, boxes, and menus (the *feel*).

Macro

A macro is a computer program that gives automated instructions to the computer (**Jacobson 2007**). In computer science it is basically a rule or pattern that specifies how a certain input sequence should be mapped to an output sequence according to a defined procedure. **Wikipedia 2009b**

Subroutine

A subroutine (also called procedure, method, function, or routine) is a portion of code within a larger program, which performs a specific task and is relatively independent of the remaining code. A subroutine behaves in much the same way as a computer program that is used as one step in a larger program or another subprogram.

ATR 72

The ATR 72 is a twin-turboprop airliner which is basically a stretched version of the ATR 42. The development program was lunched in November 1981 by Aerospatiale and Aeritalia. The P&WC PW120 turboprop power plant was chosen. The first flight of the aircraft took place on 30 April 1985 (42 version). In the same year a stretched version of the aircraft was announced at Paris Air Show. The new aircraft (with P&WC PW124B engines) had its first test fight on 20 December 1988. The ART 72 was designed according to JAR 25 certification regulations. It is a high-wing plane. Wings are of medium aspect ratio (see Table 3.1). The aircraft has T-type tail. Depends of version the ATR 72 can take up to 68 passengers (at 79 cm pitch) plus 4 members of a crew onboard.

CEASIOM

Computerised Environment for Aircraft Synthesis and Integrated Optimization Methods. This is a Matlab-based design environment for the analyses of aerodynamics, structures and flight dynamics at a very early stage of during the aircraft design process.

Visual Basic for Application

VBA is an implementation of Microsoft's event-driven programming language Visual Basic which is built into most Microsoft Office applications[1]. It can be used to control almost all aspects of the host application, including manipulating user interface features, such as menus and toolbars, and working with custom user forms or dialog boxes. Furthermore it is also possible to use VBA to create import and export filters for various file formats. **Wikipedia 2009b**

[1] It was also built into other Microsoft applications such as Microsoft MapPoint and Microsoft Visio; as well as being at least partially implemented in some other applications such as AutoCAD.

1 Introduction

1.1 Motivation

The project is a part of the aircraft design research project “Green Freighter” being carried out at the Hamburg University of Applied Sciences (HAW Hamburg). The partners of HAW in the GF project are: Airbus Future Project Office and the Institute of Aircraft Design, Lightweight Structures (IFL) of the Technical University of Braunschweig and Bishop GmbH. The aim of the GF project is to research conventional and unconventional cargo aircraft configurations. Main focus is on environmental friendly and economic aircraft operation.

The aim of this project is to improve and extend HAW Hamburg’s MS-Excel based Aircraft Preliminary Sizing Tool PreSTo. The intention of the author is to create the application which will be able to deliver quickly initial aircraft design parameters for a given mission. The issues of primary concern are to provide the user with a *convenient* tool as well as to make the application comprehensive and reliable.

1.2 Aim of the project

The main focus of this project is to improve and extend PreSTo. The project includes integration of two existing PreSTo-modules “Preliminary sizing of large propeller driven aircraft” and “Preliminary sizing of jet aircraft” as well as the set-up of an interface to CEASIOM.

The first part of the task refers to developing the new application which consists of two abovementioned modules. The integration should include all aspects of MS-Excel based application as: layout, macros, “look and feel” philosophy and others… The new tool should be designed in a way which allows the user to deal easily with all its features. Developing of new layout and structure of application requires adopting a suitable approach.

The set-up of a complete interface to CEASIOM is a complex project. The input file, which is required to start CEASIOM analysis, consists of around 700 input parameters. A lot of these parameters are provided by the already existing “Preliminary Sizing” and “Conceptual Design” PreSTo modules. However, the others have to be derived by further extension of the tool. The second part of this project sets a starting point for a compete interface to CEASIOM.

At the end, a jet and a propeller version of the regional aircraft ATR 72 should be re-designed by using the new tool. The results of all the parts of project should be presented and discussed in the report.

The report is intended to present the comprehensive description of the project workflow. However, especially the tasks like combining different macros require a great deal of time (also due to the reliability tests which have to be run). For that reason not all details can be described in the report. Where it is necessary, the references to appropriate sources are made.

1.3 Report structure

Section 2 This section describes the process of the combination of two previously developed preliminary sizing modules of PreSTo. All the aspects of the combination are presented and discussed. Section 2 contains also the description of all new features which have been developed within scope of extension and improvement of the PreSTo.

Section 3 This section deals with the CEASIOM interface. The new developed "CEASIOM input file" module of PreSTo is described in detail. The macro – which is employed by the module and is intended to produce the CEASIOM input file – is presented. Section 3 contains also descriptions of some examples of the input parameters.

Section 4 This section introduces the re-design process of the ATR 72-600 with focus on the preliminary sizing process of the jet (and propeller) version of the aircraft. The workflow of the preliminary sizing process is shown in detail. The results of the re-design process are presented and discussed.

Appendix A gives the source code of the most important macros which are employed by the preliminary sizing module of PreSTo.

Appendix B contains the source code of the macro employed by the "CEASIOM input file" module.

Appendix C presents screenshots of the "propeller" design mode of the preliminary sizing module of PreSTo.

2 Integration of the existing PreSTo modules

Within the scope of the GF project two versions of the Microsoft Excel-based Aircraft Preliminary Sizing Tool PreSTo: "Preliminary sizing of jet aircraft" and "Preliminary sizing of propeller driven aircraft" have been developed. In order to create one comprehensive tool these two modules have to be integrated. The process of integration involves combination of two modules as well as improving and extending them.

As already mentioned, the new tool is a combination of two different Excel-based applications. Therefore the process of the integration requires not only making a new application including two aforementioned modules. In many cases there is the need for a thorough redesign of certain parts of both applications. The process of integration includes four main parts:

- Design of a new structure of the tool,
- Integration of layout,
- Application of "look and feel" philosophy,
- Integration of existing macros and design of new ones,

The description of particular parts follows.

2.1 Structure of combined application

The new preliminary sizing tool can be used to re-design both jet and propeller driven aircraft. The application adopts a preliminary sizing approach described by Prof. Dieter Scholz in the lecture notes **Scholz 2009**.

According to the lecture notes the design of an aircraft is based on requirements which have to be fulfilled by the aircraft being designed. In **Loftin 1980** all the requirements are segregated into groups that refer to different flight phases: take-off, 2nd segment climb, cruise, landing and missed approach. Everything is considered simultaneously in a matching chart, which basically helps to perform a two-dimensional optimization algorithm. During the optimization we deal with two variables:

- Thrust-to-weight ratio, $T_{TO} / (m_{TO} \cdot g)$
- Wing loading, m_{MTO} / S_{W}.

The aim of the optimization, employed by the preliminary sizing process, is to assure: first, low thrust-to-weight ratio, second, suitable (high) wing loading.

The structure of the combined application refers directly to aforementioned order (template). The preliminary sizing process in the application starts with defining three performance parameters the “Design range”, R, the “Number of passengers”, n_{pax}, and the ”Cargo mass”, m_{cargo}, which are common for both design modes (jet and propeller). Therefore also in the application all these parameters are placed at the very beginning, irrespective of which version of an aircraft we want to design. See Figure 2.1.

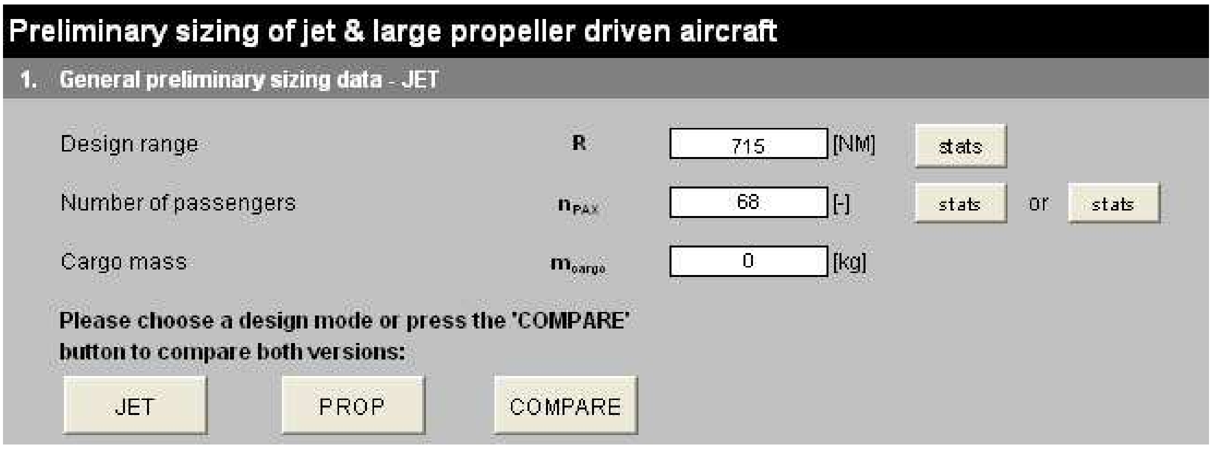

Figure 2.1 General preliminary sizing data in PreSTo

The next step after providing all the three values is to decide which design mode we want to run. After we press a button the appropriate version of the application will be activated. The user can also press the “COMPARE” button to activate both versions in order to collate them with each other.

To describe the structure of next parts (sub-modules) of the combined application we use – as an example – the jet version. After pressing the “JET” button a set of “Comparison parameters” as well as all the others sub-modules of the jet version appear on a screen. The “Comparison parameters”, seen in Figure 2.2, include:

- Max. Take-off mass, m_{MTO},
- Max. landing mass, m_{ML},
- Operating empty mass, m_{OE},
- Mission fuel fraction for standard flight, m_F,
- Wing area, S_W.

All these parameters are basically the values which will be compared with the results of the preliminary sizing process at the very end.

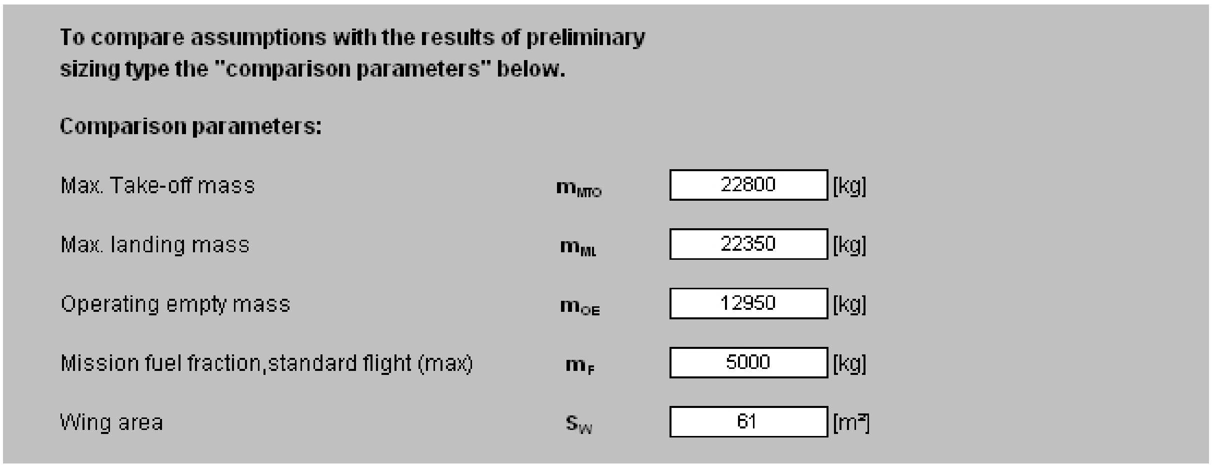

Figure 2.2 “Comparison parameters”

If the user has a rough idea of what these parameters should be, they can fill in the appropriate boxes (white cells), to have an opportunity to assess the results in the last part of application. See Figure 2.5.

The next six sub-modules refer to different flight phases as follows (see Figure 2.3):

- Approach
- Landing
- Take-Off
- 2nd segment
- Missed approach
- Max. glide ratio in cruise.

In these sub-modules the user has to insert the number of input parameters. The way in which it should be done is described in Section 2.2.

Figure 2.3 PreSTo jet version’s structure (sub-modules)

In Figure 2.3 we can see also the “Matching Chart” and the “Preliminary Sizing” sub-modules. “Matching Chart” is basically a diagram in which all aforementioned phases of flight are represented by appropriate curves, as seen in Figure 2.4.

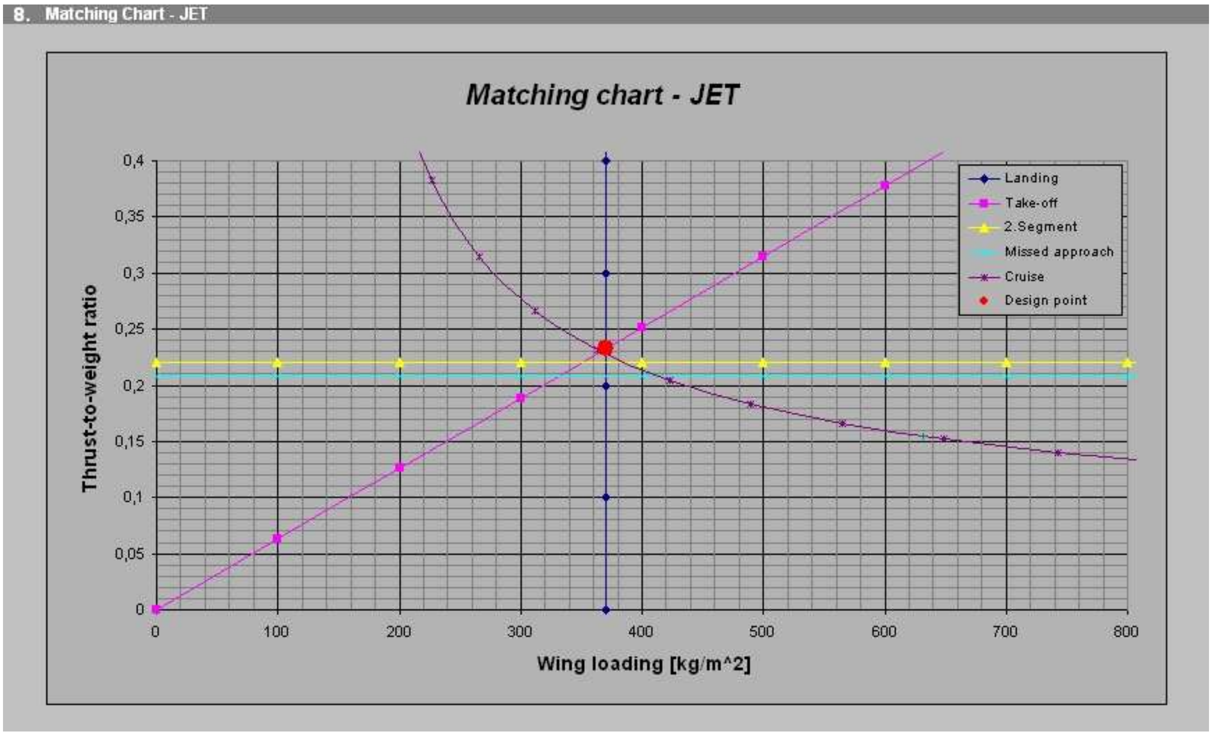

Figure 2.4 Matching chart in PreSTo (jet version)

The chart is created according to a special template which was developed to make sure that the data are presented in a clear way (see Table 2.1).

Table 2.1 Format template for the matching chart

Feature	colour	weight	line/ font style	font	font size	tick mark
x-axis	Black	Thin	Continuous	-	-	Outside
x major gridline	Black	Thin	Continuous	-	-	-
x minor gridline	Gray 50%	Thin	Continuous	-	-	-
x-axis label	Black	-	Normal	Arial	12	-
x-axis title	Black	-	Bold	Arial	12	-
y-axis	Black	Thin	Continuous	-	-	Outside
y major gridline	Black	Thin	Continuous	-	-	-
y minor gridline	Gray 50%	Thin	Continuous	-	-	-
y-axis label	Black	-	Normal	Arial	12	-
y-axis title	Black	-	Bold	Arial	12	-
foreground	Gray 25%	-	-	-	-	-
background	*Farbschema*	-	-	-	-	-

The last sub-module called the “Preliminary Sizing” includes: a choice of certification base, a choice of a type of an aircraft as well as fuel fractions calculations and presentation of all the results at the end. As mentioned before, this sub-module allows the user to compare the results with the assumptions. See Figure 2.5.

Original aircraft data:				Redesign? Compare with results!			Calculated aircraft data:	
Max. Take-off mass	m_{MTO}	22800	[kg]	↔	Max. Take-off mass	m_{MTO}	22524	[kg]
Max. landing mass	m_{ML}	22350	[kg]	↔	Max. landing mass	m_{ML}	21285	[kg]
Operating empty mass	m_{OE}	12950	[kg]	↔	Operating empty mass	m_{OE}	11487	[kg]
Mission fuel fraction, standard fligh	m_F	5000	[kg]	↔	Mission fuel fraction, standard flight	m_F	4713	[kg]
Wing area	S_W	61	[m²]	↔	Wing area	S_W	60,9	[m²]

Figure 2.5 The comparison of the results and the assumptions

As is often the case, during the re-design process of a certain aircraft we want to keep these six values (Max. take-off mass, Max. landing mass, Operating empty mass, Mission fuel fraction for standard flight and Wing area) at a lower level than original ones. For that reason, if a result value is lower than a value we assumed at the beginning, the particular cell will be marked with a green colour (and a green frame), as seen in Figure 2.5. If a result is bigger than an assumption, text in a cell (and frame) will be red.

2.2 Layout

The layout description deals with the rules applied during the design process of the combined preliminary sizing module of PreSTo. In this case, the design process refers to the implementation of a *clear* graphic template as well as to adopting the particular philosophy of arrangement of all the objects[2] in the preliminary sizing module. The elaborate description of the layout follows.

The graphic design of the new preliminary sizing module employs the approach described in **Wolf 2009**. In general, the module consists of three types of fields:

- Module title
- Sub-module title
- Calculation & Presentation.

Each of them has a particular task. The “Module title” and the “Sub-module title” fields basically inform the user about a name of a particular module or a sub-module, respectively. All the elements and objects like input cells, graphs, buttons, drop-down lists, etc. are placed in the “Calculation & Presentation” fields. See Figure 2.6.

[2] The application employs for instance: input cells, result cells, buttons, dropdown lists, etc.

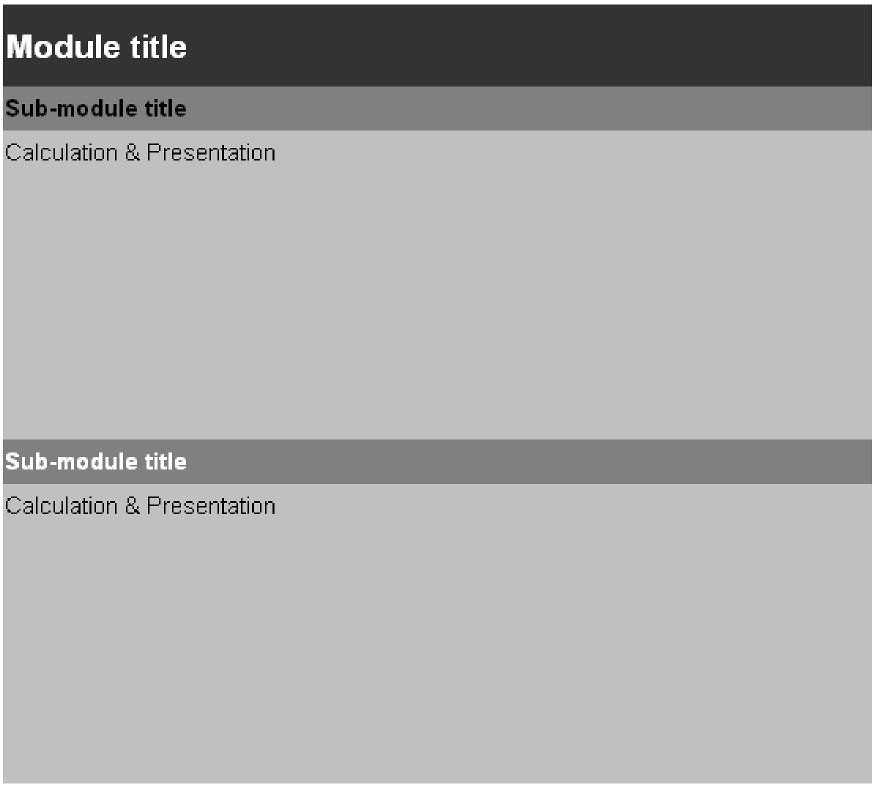

Figure 2.6 The general layout pattern in the preliminary sizing module of PreSTo

Due to two design modes of preliminary sizing module (jet and propeller) the font of the "Sub-module title" can be either black or white. The jet mode employs a white color and the propeller mode uses a black one. The details about format of described fields are given below. See Table 2.2.

Table 2.2 Format of general layout fields

Type of field	Font	Style	Size of font	Font text colour	Background colour	Height of cell [pixels]
Module title	Arial	Bold	14	White	Black	35
Sub-module title	Arial	Bold	10	Black/White	Grey 50%	18
Calculation & Presentation	Arial	-	10	Black	Grey 25%	18

After choosing a design mode the user mainly deals with "Calculation & Presentation" fields. During creating the new application the jet version fields were re-design in order to make them as similar as possible to the propeller version fields. The re-design process was intended to make the new preliminary sizing module more convenient and intuitive to use. The re-design of the jet version fields is based upon the design philosophy described in **Wolf 2009**. As we can see in Figure 2.7 all the input cells and cells filled in with given values are placed on the left-hand side. All the "calculations" and the results of these calculations are situated on the right-hand side. Also general rules regarding input cells' layout are followed. As proposed in **Luthra 2008**, a background colour of all the input cells is white. The "Non-input" cells have the same background colour as "Calculation & Presentation" fields (Grey 25%).

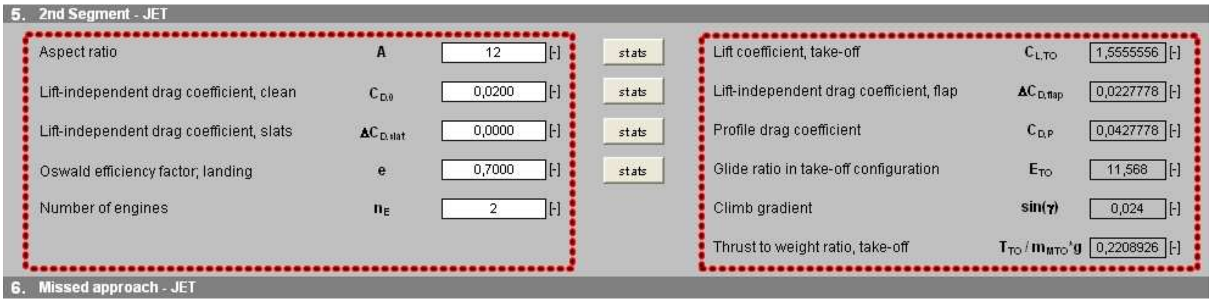

Figure 2.7 Layout's design philosophy

If some value from "calculations and results" side is a function of a particular value placed in "input and given values" side, then these two cells are "connected" with a black arrow. See Figure 2.8.

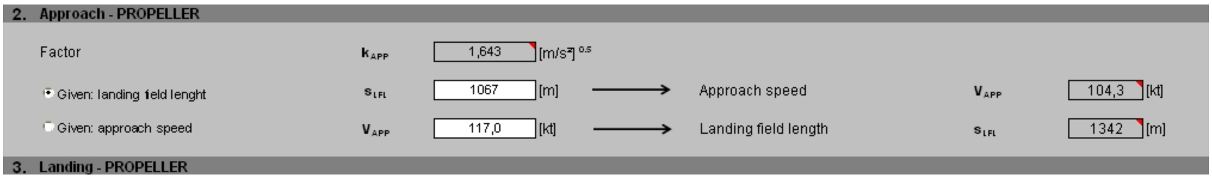

Figure 2.8 Black arrows indicate relations between cells' values.

If statistic data are available, then the "stat" button is placed by a particular cell, as seen in Figure 2.9. The aim of the "stat" button is to direct the user to another spreadsheet, called "statistics". The user can check the statistical data in order to support a decision process. More details about the "statistics" module are given in Section 2.4.

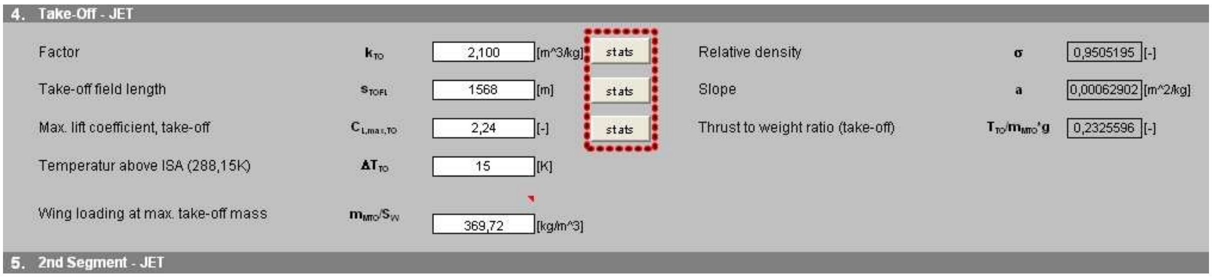

Figure 2.9 Position of the "stat" buttons

The "statistics" module is still in the development phase. It is beyond the scope of this project to provide statistical data references for every input value in the "preliminary sizing" module. However, basic layout standards for the "stat" buttons have to be set in order to make the further development easier.

A "stat" button is basically a control element, called a command button. The command button is typically used to start an event that performs an action such as closing the form, printing a report and etc. As mention before, in case of the preliminary sizing module the "stat" button is used to moving to the "statistics" spreadsheet. The details about the layout format of the "stat" button are shown in Figure 2.10.

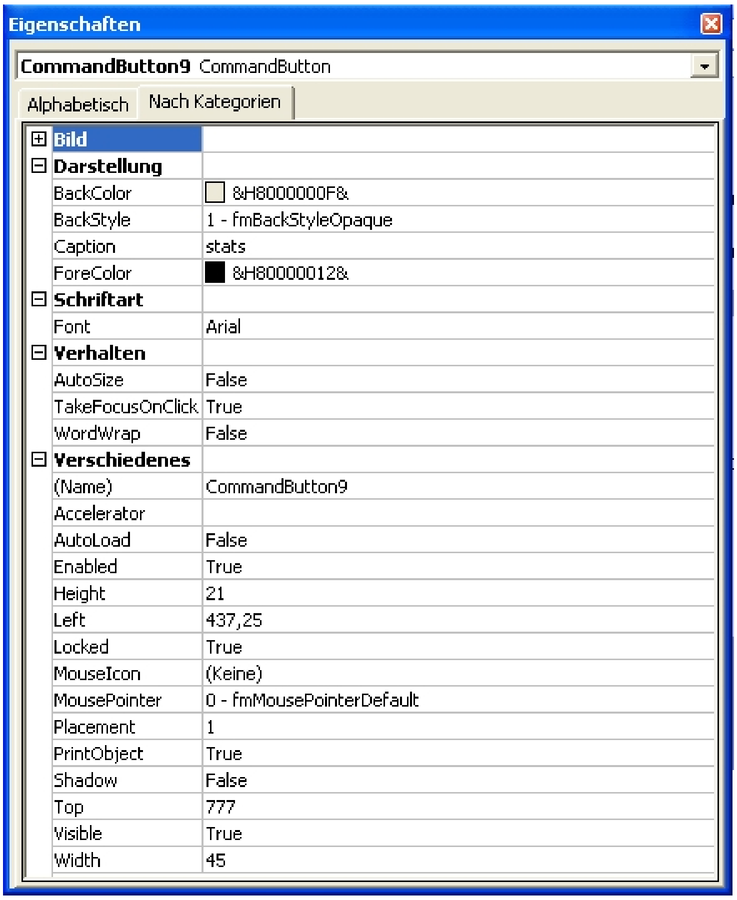

Figure 2.10 Layout format of a stat button

Take a notice of the crucial properties of the “stat” button which are:

- Size (Height and Width)
- Horizontal location (Left)
- Placement

The “Placement” property needs to be set to “1”, otherwise some errors can occur during choosing of a design mode of the preliminary sizing process. Vertical location (Top) is not taken into account because that value is different for each button. The values of the rest of properties – that are necessary to crate a control element – are default.

During developing of the preliminary sizing module of PreSTo also the “look and feel” philosophy was employed. When it comes to the preliminary sizing process there is often the need of updating or comparing different design or input parameters. For that reason, within the scope of the “look and feel” philosophy, grouping and ungrouping option was applied. “Grouping and ungrouping” option provides the user with an opportunity to hide or activate particular groups of rows. After filling in all the input cells a “Calculation & Presentation” field of a particular sub-module can be hidden and the user is able to start to work with the next sub-module. If necessary a “Calculation & Presentation” field of any previous sub-module can be activated. For instance, if the user has got to check the values from the “Approach” sub-module during the work with the “2nd Segment” sub-module, then it is not necessary to scroll up a big part of spreadsheet. It is possible to activate a particular sub-module by clicking once on a “activate or deactivate” box by the sub-module on the very left-hand side of the spreadsheet. The example is shown in Figure 2.11.

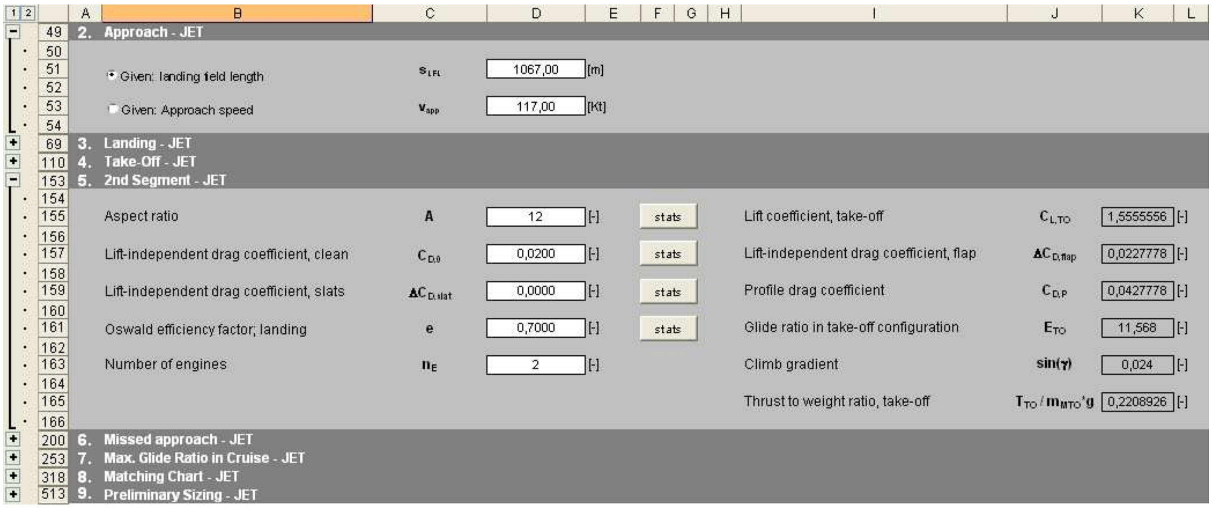

Figure 2.11 The application of the “feel and look” philosophy

There is also a possibility of activating or deactivating all of the grouped fields. If the user presses the “activate or deactivate” box number 1 (placed in the left right corner of the spreadsheet), all the grouped fields will be activated. In case of pressing the box number 2, all these fields will be closed. An elaborate explanation of how to apply the “grouping and ungrouping” option can be found in **Wolf 2009**.

2.4 Macros

PreSTo comprises the number of macros, which significantly improve the application performances. Also new subroutines, which enhance new features of PreSTo, were written as well. Due to the fact that subroutine is a kind of a macro, in this report all the described subroutines are called macros.

PreSTo is based on MS-Excel application. For that reason all the macros were written as the Visual Basic for Application (VBA) code.

During the integration of jet and propeller PreSTo modules new macros have been developed. However the new preliminary sizing module had to be also integrated with statics modules, what required modification of previously created macros.

Considering a complex macro, at some point a number of lines of a code becomes so great that it is crucial to establish overall standards for a layout of a macro’s code[3]. For that reason a special template was created. The template states how particular parts (tile, sub-title, comments…) of a code should be written.

The template of a macro layout deals with four major parts:

- Name of a macro,
- Description of a macro,
- Head comment line,
- Side comment line.

In addition, there are also rules which treat whit a code structure. The example of a macro coded according to the template is given in Figure 2.12.

On the screenshot we can see the structure of a code of the macro called “ActivateJetMode”. For reasons of simplicity the first line of the code, which is written at the very beginning, should include a name of the macro. In addition, the name should somehow refer to a task of the macro.

After the first line the “Description of the macro” follows. A description includes: a full name of the macro, a short description of the task, the name of an author and the contact line (in case of any questions or problems with compilation). A single line of the “Description of the macro” should not be longer than 80 digits in order to provide the code which is convenient to read.

The “Head comment line” says what the following part of a code deals with. If an additional comment or remark is necessary, then the “Side comment line” can be added. The “Side comment line” should start with the 81st digit of a particular line of a code. A line of a source code should not be longer than 80 digits.

[3] It is also important because of the fact that PreSTo is being continuously improved and extended by a group of engineers and students, who in general, should follow the same rules of the layout implementation.

Name of the macro

Description of the macro

Side comment line

Head comment line

```
Private Sub ActivateJetMode_Click()

'*******************************************************************************
'
' ActivateJetMode
'
' Activates the jet mode of the preliminary sizing module and deactivate
' both proppeler and compare mode
'
' Author:  Marcin Lenarczyk, Warsaw University of Technology
' Contact: Hamburg University of Applied Sciences, AERO Group
'*******************************************************************************

' Hiding of "propeller rows"

    Application.Goto Reference:="area_0p, area_2p, area_3p, area_4p"          '<<< area_#p is name of a
    Selection.RowHeight = 0                                                    '<<< particular set of cells
    Application.Goto Reference:="area_7p, area_8p, area_5p, area_6p"
    Selection.RowHeight = 0
    Application.Goto Reference:="area_9p, mat_chart_prop, area_10p, area_11p"
    Selection.RowHeight = 0

' Unhiding of "jet rows"

    Application.Goto Reference:="area_0j,area_2j, area_3j, area_4j, area_5j, area_6j"
    Selection.RowHeight = 14.25
    Application.Goto Reference:="area_7j, mat_chart_jet, area_8j"
    Selection.RowHeight = 14.25

    ThisWorkbook.Sheets("preliminary sizing").Range("B4").Select

    ActiveSheet.Outline.ShowLevels RowLevels:=1

' Formating of the title of sub-module

    Range("A2").Select
    With Selection
        .Font.ColorIndex = 2
        .Font.Bold = True
    End With

    Range("B2").Select
    With Selection
        .Font.ColorIndex = 2
        .Font.Bold = True
        .FormulaR1C1 = "General preliminary sizing data - JET"             '<<< sub-module title
    End With

    Range("B4").Select

End Sub
```

Figure 2.12 The template of a macro's layout

The preliminary sizing module of PreSTo employs three major macros: "ActivateJetMode", "ActivatePropMode" and "ActivateCompareMode". All the three macros deal with changing of a design mode.

The "ActivateJetMode" basically activates the jet mode of the preliminary sizing module of PreSTo. The macro hides all the rows of the spreadsheet which belong to the propeller mode and shows all the rows of the jet mode. By hiding and showing we understand changing of height of particular cells to 0 pixels or 18 pixels, respectively. The macro also changes the first sub-module title for "General preliminary sizing data – JET". The macro is initiated by the control form[4] (button) called "JET" (see Figure 2.1). For the further details see Appendix 1.

---

[4] Controls are the primary medium of user interaction. By typing and clicking and by moving through controls on the forms in your application, users can manipulate their data and accomplish the tasks they want to do.

The "ActivatePropMode" and the "ActivateCompareMode" macros are activated by "PROP" and "COMPARE" control forms, respectively. These macros work in the same way as the "jet" one does (by hiding and showing particular sets of cells). The task of the compare mode is described in the Section 2.1.

The preliminary sizing module deals also with the macro which provides statistics data for the number of input parameters. The macro is initiated by the control forms (buttons) called "STAT". After initiation the macro activates the "Statistics module" (the "statistics" spreadsheet), as seen in Figure 2.13.

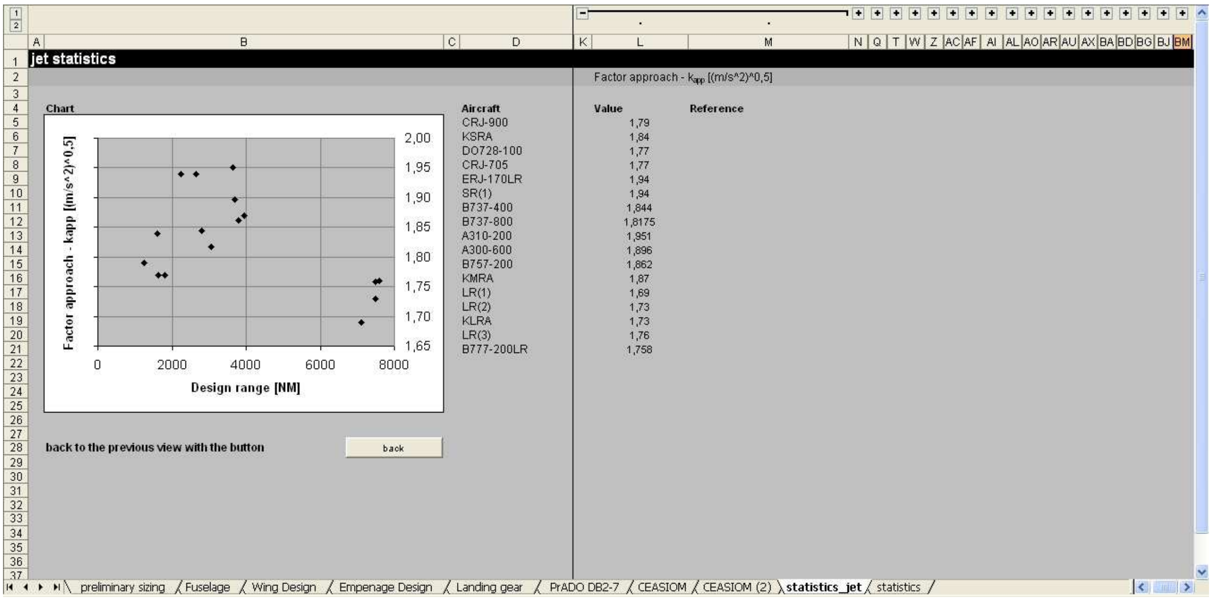

Figure 2.13 The statistics module

Then two appropriate columns are being selected in order to create a series of data, which will be presented in a chart. The macro deals also with a format of the chart (see Table 2.3). A special template was developed to make sure that the data are presented in a clear way. The "stat" macro was originally written by Sebastian Wolf. The updates were made by the author of the report. For further details see Appendix 1.

Table 2.3 Format template for the chart in the statistics module

Feature	colour	weight	line/ font style	font	font size	tick mark
x-axis	Black	Thin	Continuous	-	-	Outside
x major gridline	Gray 50%	Thin	Continuous	-	-	-
x minor gridline	-	-	-	-	-	-
x-axis label	Black	-	Normal	Arial	12	-
x-axis title	Black	-	Bold	Arial	12	-
y-axis	Black	Thin	Continuous	-	-	Outside
y major gridline	Gray 50%	Thin	Continuous	-	-	-
y minor gridline	-	-	-	-	-	-
y-axis label	Black	-	Normal	Arial	12	-
y-axis title	Black	-	Bold	Arial	12	-
foreground	Gray 25%	-	-	-	-	-
background	White	-	-	-	-	-

3 CEASIOM interface

Present trends in aircraft design towards augmented-stability and expanded flight envelopes call for an accurate description of the non-linear flight-dynamic behaviour of the aircraft in order to properly design the Flight Control System (FCS). Hence the need to increase the knowledge about stability and control (S&C) as early as possible in the aircraft development process in order to be "First-Time-Right"; with the FCS design architecture.

FCS design usually starts near the end of the conceptual design phase when the configuration has been tentatively frozen and experimental data for predicted aerodynamic characteristics are available. Up to 80% of the life-cycle cost of an aircraft is cost of the conceptual design phase so mistakes must be avoided. Today prediction errors related to S&C result in costly fly-and-try fixes, sometimes involving loss of proto-type aircraft and crew.

For that reason a Specific Targeted Research Project called SimSAC (Simulating Aircraft Stability And Control Characteristics for Use in Conceptual Design) has been set. The research project is financed by the European Union. Within the scope of the project a simulation environment, CEASIOM, has been created and implemented for conceptual design sizing and optimisation. Furthermore the simulation environment is being still developed.

CEASIOM, the Computerised Environment for Aircraft Synthesis and Integrated Optimization Methods, is a framework tool that integrates discipline-specific tools for conceptual design. At this early stage of the design it is very useful to be able to predict the flying and handling qualities of this design. In order to do this, the aerodynamic database needs to be computed for the configuration being studied which then has to be coupled to the stability and control tools to carry out the analysis (**Grabowski 2009**).

Within the scope of this project a CEASIOM interface has been developed and applied into PreSTo. By the CEASIOM interface we understand a MS-Excel spreadsheet which is intended to “produce” CEASIOM input file. The input file should employ parameters calculated during the preliminary sizing and the conceptual design process carried out in PreSTo.

3.1 CEASIOM module of PreSTo

The “CEASIOM input file” module comprises of two major parts. The firs one is the so-called “User interface”. The “User interface” is situated on the left-hand side of the spreadsheet, as can be seen in Figure 3.1. The field with a white background is the so-called “Code part”. The “Code part” basically includes the source code which creates the CASIOM input file.

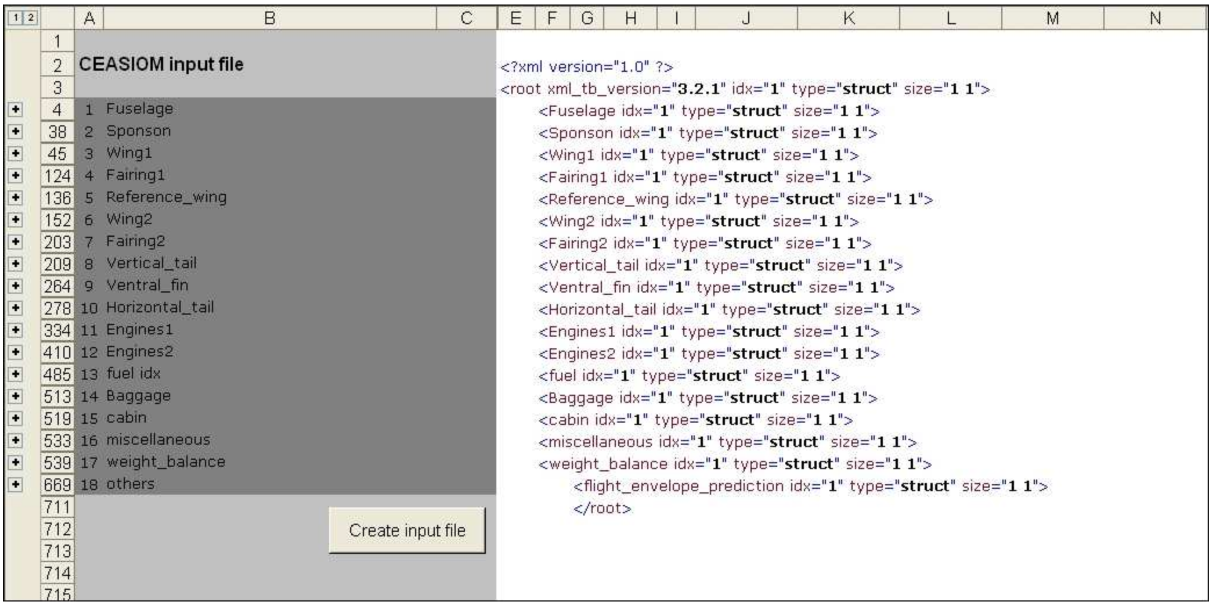

Figure 3.1 The layout of the "CEASIOM input file" module

The "User interface" employs the general layout rules adopted by the preliminary sizing module. For that reason also the "CEASIOM input file" features "drop-down lines" which allow the user to activate and deactivate different parts of the spreadsheet. In Figure 3.1 we can see only a part of the source code. The whole code structure can be seen after activating all the parts of the spreadsheet. The structure of the code was divided into 18 main parts (sub-modules of the "CEASIOM input file" module), as follows:

- Fuselage,
- Sponson,
- Wing 1,
- Fairing 1,
- Reference wing,
- Wing 2,
- Fairing 2,
- Vertical tail,
- Ventral fin,
- Horizontal tail,
- Engines 1,
- Engines 2,
- Fuel idx,
- Baggage,
- Cabin,
- Miscellaneous,
- Weight balance,
- Others.

In Figure 3.2 we can see the module with the activated “Fuselage” sub-module.

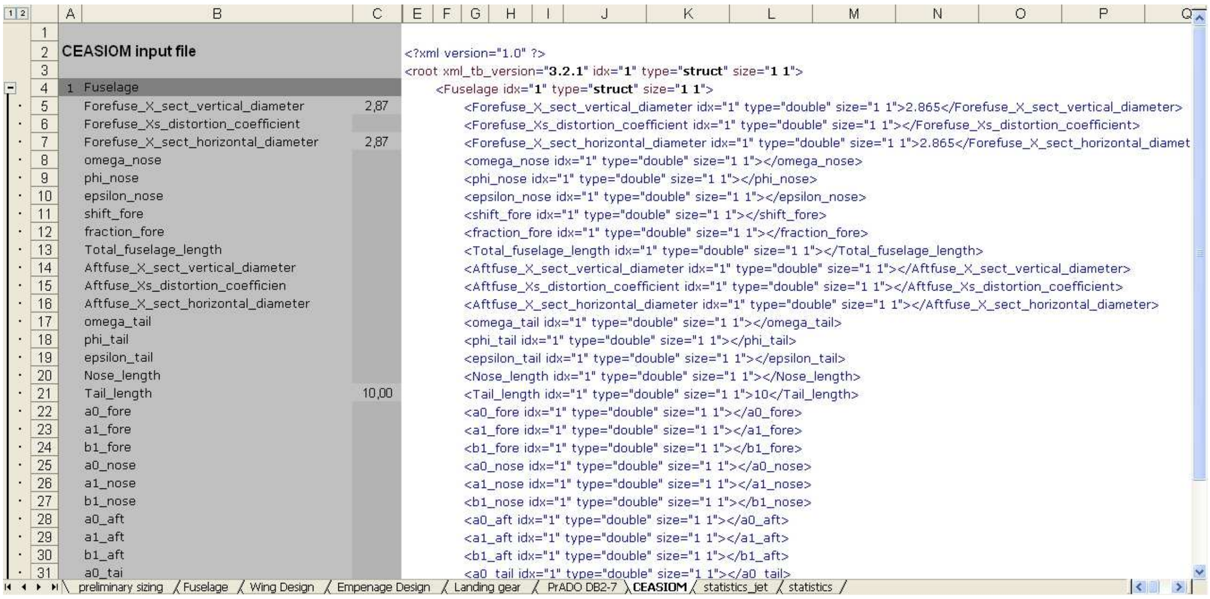

Figure 3.2 The “Fuselage” sub-module of the “CEASIOM” input file

The structure of the code of a particular sub-module consists of the header (title line), “main code” and the “end” line of the code. Each type of the instructions is shown in Figure 3.3.

```
<Fuselage idx="1" type="struct" size="1 1">

    <Nose_length idx="1" type="double" size="1 1">1.5</Nose_length>
    [...]

</Fuselage>
```

Figure 3.3 The structure of the code of CEASIOM input file

As we can see both the header and the “end” line include the name of the sub-module. The “main code” line consists of the name of the particular parameter, the type of a variable and the value of the variable. In the example given above the name of variable is “Nose length” and the value is 1.5.

The “CEASIOM input file” employs a macro which basically creates a separated file which consists only of the source code. The macro is initiated by the “Create input file” control form (button), as seen in Figure 3.1.

In the first step the macro called “create_input_file” activates all the cell of the “CEASIOM input file” spreadsheet which contains the source code of the input file. Than the code is copied and pasted into the new MS-Excel spreadsheet and the message box is activated. See Figure 3.4.

Figure 3.4 Massage box 1

That means that the new MS-Excel file has been created. For reason of reliability the new file has to be saved by the user manually[5]. The second massage box informs the user about that, as can be seen in Figure 3.5. The user has to save the file in “.xml” format. To do this the following action should be undertaken: *File/Save as/File format/(.xml)/Save*.

Figure 3.5 Massage box 2

The source code of the “create_input_file” can be found in Appendix B.

The number of input parameters is generated automatically by the spreadsheet. That means that some input cells in the “CEASIOM input file” module are connected directly to “result” cells of the preliminary sizing and conceptual design modules. As can be seen in Figure 3.2 if the input parameter is given automatically the background of the input cell is of the same colour as the background of the “parameter name” cell (Grey 25%). Otherwise, the colour of the background of the input cell is “Grey 50%”. The values of the cells which are not filled in automatically have to be defined by the user manually.

It is beyond the scope of the project to define all the input parameters in the “CEASIOM input file” module (CEASIOM employs nearly 700 input parameters). The more important is to provide the reliable user interface which can be developed and further extended in the future.

To give the user an overall impression of how the input parameters are defined the definitions of two of them follows. The description of input parameters, which are generated automatically in the “CEASIOM input file” module, builds on the report **Puelles 2009**.

---

[5] Of course it is possible to create a macro which would save a new MS-Excel file automatically. However, it requires giving the address of the particular folder in the macro’s code in order to save the new file. In such a case that macro would only be compiled in that particular computer for which the given address of the folder is valid.

The name of the first presented parameter is “Forefuse_X_sect_vertical_diameter”. It is basically vertical diameter (in meters) of the first cross-section of the centre fuselage. It is represented in Figure 3.6 as d_v.

The “Forefuse_X_sect_horizontal_diameter” is the horizontal diameter of the first cross-section of the centre fuselage. It is represented in Figure 3.6 as d_h.

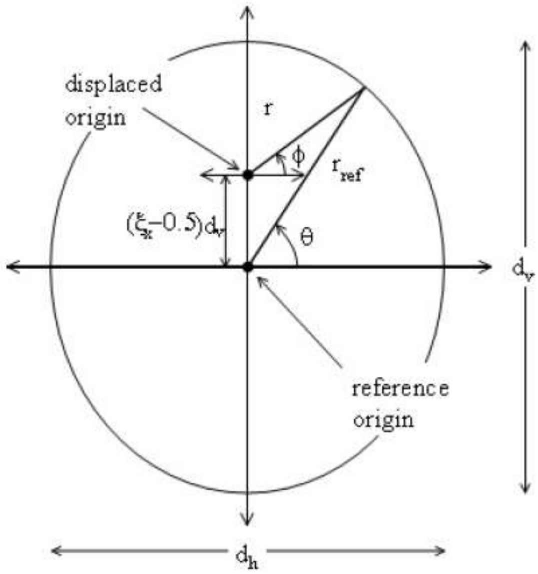

Figure 3.6 Geometrical definition of centre-fuselage cross-section

4 Re-design of a jet and a propeller variant of the regional aircraft ATR 72

Within the scope of the project the re-design process of both jet and propeller versions was carried out. The re-design of the aircraft has two major aims. The first aim is to validate the new preliminary sizing module of PreSTo. The second one is to give to the reader an overall impression of the new tool.

Within the scope of the validation propeller and jet version of the ATR 72-600 were re-designed in order to asses the results of the preliminary sizing process with respect to the real data of the reference aircraft.

It is also crucial to provide the reader with an idea of how exactly the new preliminary sizing module works. The reader is introduced to the principle design steps and requirements posed to an aircraft in general as well as to the way the tools deals with those tasks.

4.1 Overview

The re-design process refers to the ATR 72-600 version which will feature the latest technological enhancements while building upon the well-known advantages of the current aircraft. It will include the new PW127M as standard engine and Glass Cockpit flight deck featuring five wide LCD screens. In addition, a multi-purpose computer will further enhance Flight Safety and operational capabilities. The new avionics, to be supplied by Thales, will also provide CAT III and RNP capabilities. The -600 series ATR aircraft will be progressively introduced during the second half of 2010. Performance data of the aircraft are shown in Table 4.1.

Table 4.1 Performance of ATR 72-600 (provided by the manufacturer and **Jane's 2007**)

Measurement	Value
Length	27,16 m
Wingspan	27, 06 m
Height	7, 65 m
Range	715 nm (1324 km)
Max. Speed	511 km/h
Max. Take-off Weight	22 800 kg
Operating Empty Weight	12 950 kg
Payload (for given Range)	7 790 kg
Max. Fuel Weight	5000 kg
Take-off Field Length	1568 m
Land. Field Length	1067 m
Service Ceiling	7 620 m

The application of the preliminary sizing module of PreSTo to the ATR 72-600 is presented with respect to the jet version of the aircraft. During the combination of the two previously developed preliminary sizing modules much more changes were made in the jet one. For that reason the validation of that version is of the primary concern. The presentation of the preliminary sizing process builds on **Seeckt 2008**.

4.2 Determination of the aircraft design point

The first step in the preliminary sizing process is to determine the so-called aircraft design point which includes wing loading m_{MTO} / S_W and thrust-to-weight ratio $T_{TO} / (m_{TO} \cdot g)$ values. In the second step the number of aircraft parameters like masses, thrust, the wing area, etc. is calculated with respect to the previously determined design point.

The following five requirements, which have to be fulfilled by an aircraft (according to American and European certification regulations), lead to the design point:

- Landing distance, s_{lf},
- Take-off distance, s_{to},
- Take-off climb gradient, $sin\ (\gamma_{to})$,
- Missed approach climb gradient, $sin\ (\gamma_{missed\ app})$,
- Cruise Mach number, M_{cr}.

Each of the requirements delivers a value for either wing loading, thrust-to-weight ratio or the relation of the two. Than all the values are plotted into the matching chart in order to make it possible to find the aircraft design point. As mentioned in Section 2 the aim of the optimization, employed by the preliminary sizing process, is to assure: first, low thrust-to-weight ratio, second, suitable (high) wing loading.

4.2.1 General preliminary sizing data

Before providing the input parameters for the first requirement the general aircraft data as well as the type of the propulsion system have to be given by the user. The preliminary sizing process of the ATR 72-600 (jet version) starts with these two steps, as shown in Figure 4.1.

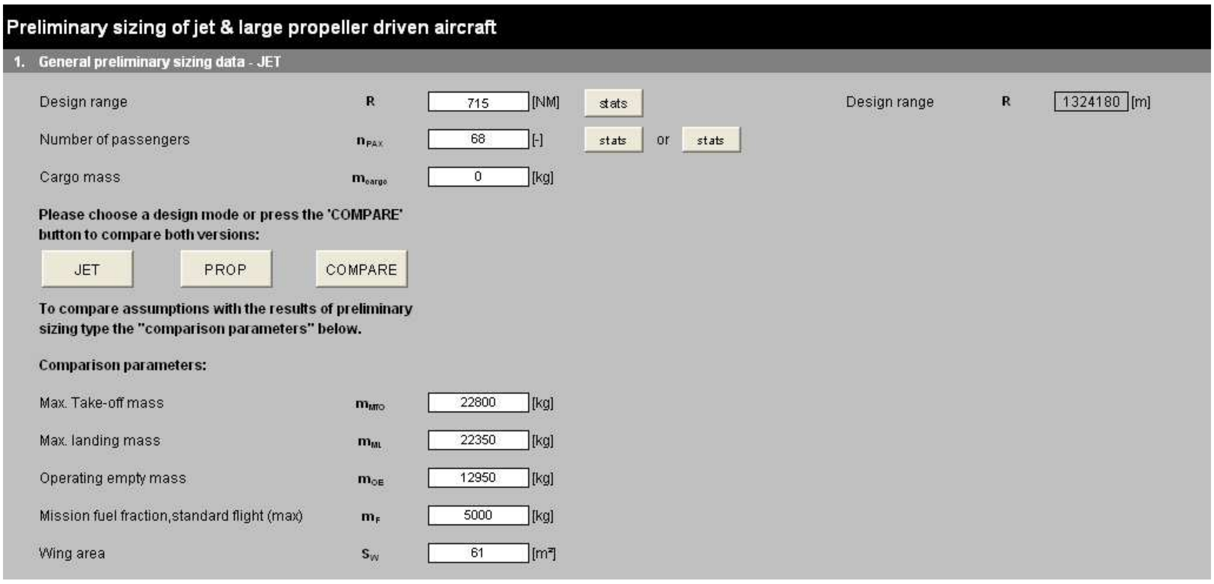

Figure 4.1 General preliminary sizing data

The “Design range” and the “Number of passengers” values are 715 nm and 68 persons, respectively (according to the data provided be the manufacturer). The “Cargo mass” is a mass of an additional load which is not taken into consideration in case of “Payload” (mass of passengers, their baggage and crew). Because the ATR 72-600 does not take a cargo mass onboard, the value for that parameter is given as zero. After choosing the jet version by pressing the appropriate button, the “Comparison parameters” can be typed. The values for masses are given as follows (**Janes 2007**):

- Take-off – 22800 kg,
- Landing – 22350 kg,
- Operating empty – 12950 kg.

The “Mission fuel fraction” for standard flight and the “Wing area” are 5000 kg and 61 m^2, respectively.

4.2.2 Landing distance

The next step is the landing distance requirement which delivers a maximum value for the aircraft’s wing loading. The basis for analyzing the landing distance are aviation regulations. An aircraft may land at an airfield if the landing field length, s_{LFL}, is shorter than the landing distance available, s_{LDA}.

The landing distance value cannot be exceeded at a given landing distance. The algorithm employed by the preliminary sizing module of PreSTo does not use the landing distance directly but the approach speed, V_{APP}. The approach speed is defined in the certification specifications (CS-25, FAR Part 25) as not less than 1.3 times the stall speed, V_S, of an aircraft. For that reason it is not necessary to know a landing distance value. The user of PreSTo has a choice and instead of providing a landing distance value one can simply give an approach speed value. In case of the ATR 72-600 the landing length is known (**Janes 2007**). The appropriate option has been chosen and the value (1067 m) has been typed, as seen in Figure 4.2.

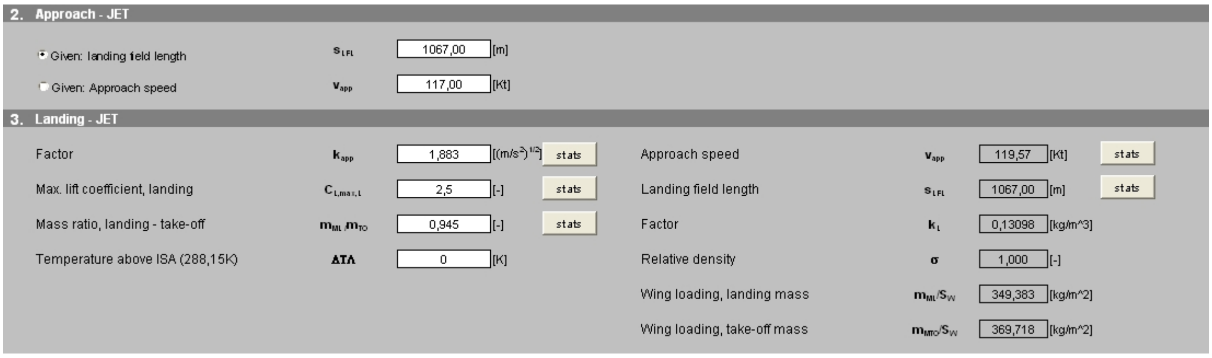

Figure 4.2 Approach and Landing

In figure 4.2 we can see also the "Landing" sub-module which directly refers to landing distance requirements. k_{app} is basically a correlation factor and it is a necessary value to calculate the approach speed. The correlation between a landing distance and an approach speed is described in **Loftin 1980**. For the reference aircraft the k_{app} equals 1.883 $(m/s^2)^{1/2}$. The value was taken from the "statistics" module, as seen in Figure 4.3. The "statistics" spreadsheet provides the landing field length correlation factor as a function of "Range".

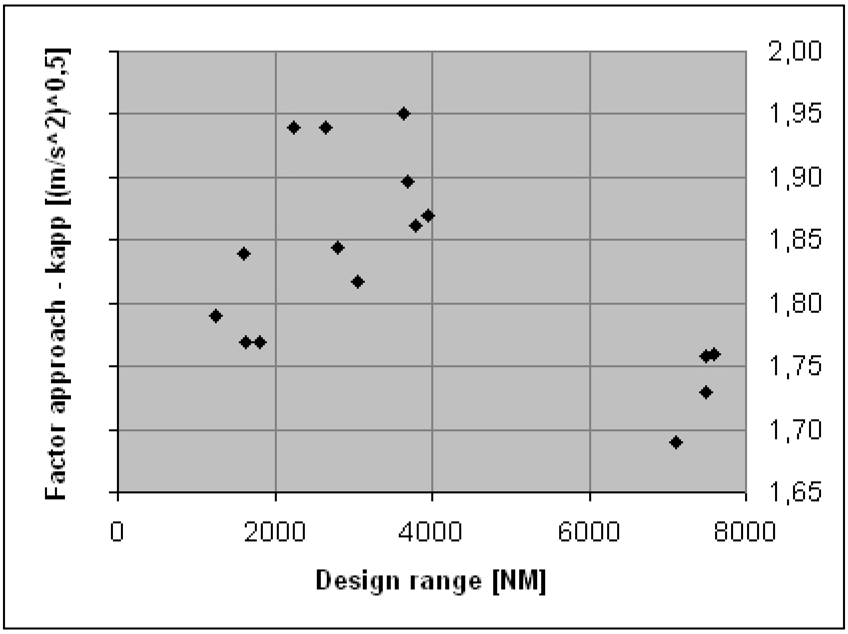

Figure 4.3 The landing field length correlation factor as the function of "Range"

The "Max. lift coefficient for landing" and the mass ratio of the landing mass to the take-off mass are 2.5 and 0.954, respectively. The "Max. lift coefficient for landing" estimation is based on theoretical performances of high-lift devices (see Figure 4.4). At this point it is important to add that max. lift coefficient for landing phase has to be estimated very carefully. The user can of course relay on the statistics data provided by the application. However, the estimation must be carried out with respect to all the high-lift systems which are featured by an aircraft. The "Temperature above ISA", $\Delta T\Delta$, (International Standard Temperature) is given as 0 K.

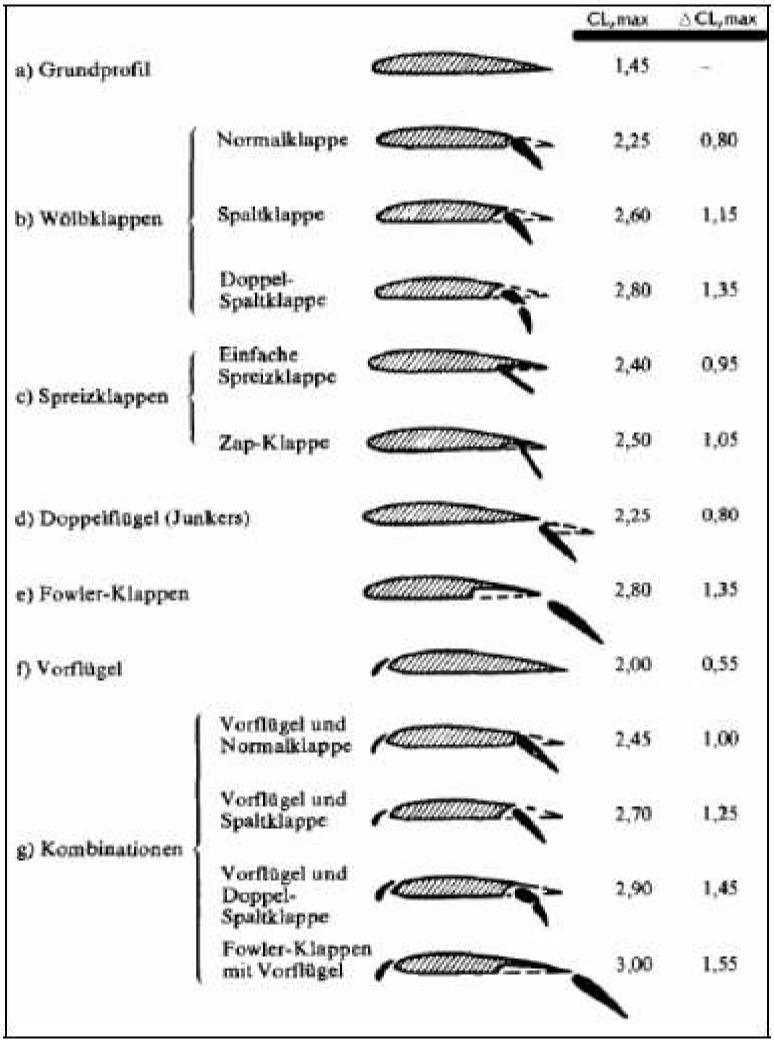

Figure 4.4 Maximum lift coefficient of different lift devices (**Dubs 1966**)

4.2.3 Take-off distance

In the next step the take-off distance requirements are taken into consideration. In general, the requirements refer to an engine failure during take-off. The detailed comment of the aviation regulations which treat with the take-off distance requirement can be found in **Scholz 2009**.

The "Take-off" sub-module delivers a relation between the thrust-to-weight ratio and the wing loading that an aircraft has to show at least in order to fulfill the abovementioned requirement. In this case the algorithm also employs a correlation factor. For the ATR 72-600 the take-off correlation factor is 2.1 m^3/kg. The factor is derived form statistics as well (see Figure 4.5).

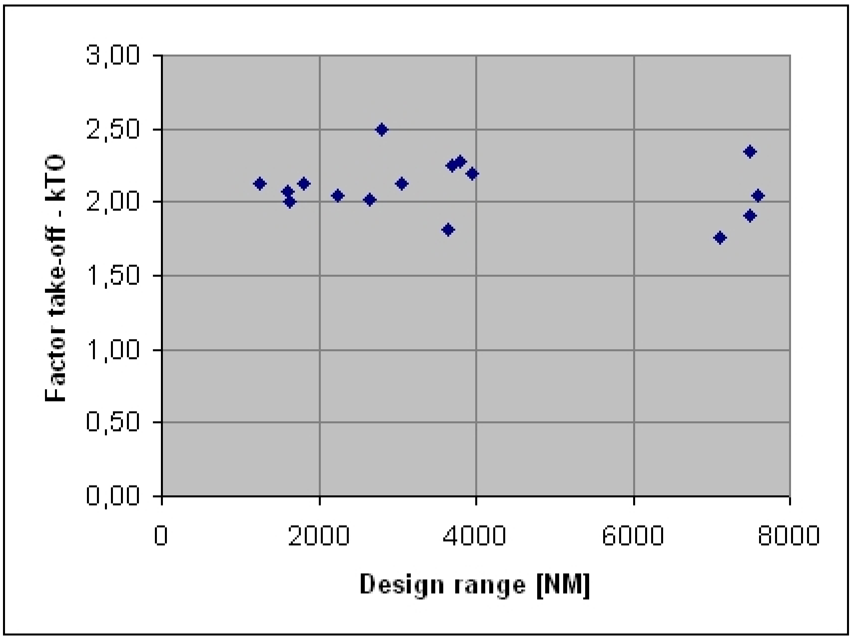

Figure 4.5 Take-off correlation factor as the function of "Range"

According to data provided by the manufacturer, the "Take-off field length" is given as 1568 m, as seen in Figure 4.6. Max. lift coefficient for the take-off flight phase is lower than for the landing phase and it is equal to 2.24. The value of the max. take-off lift coefficient, if known, can be entered directly into PreSTo or otherwise is assumed to be 80% of the maximum landing field coefficient. The temperature above ISA and the wing loading ratio are 15 K and 369.72 kg/m^3, respectively.

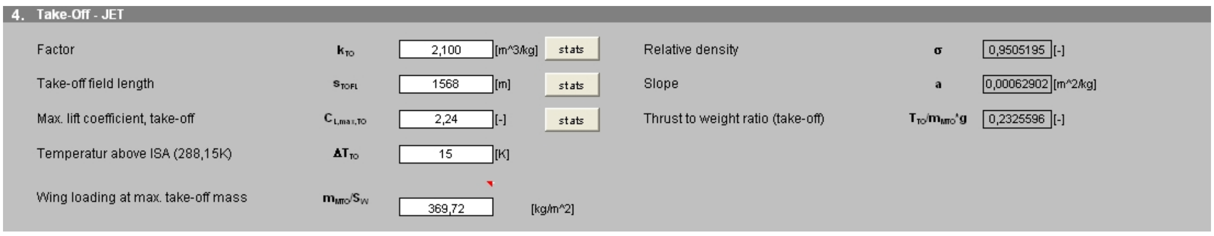

Figure 4.6 Take-Off

In the contrary to the "Landing" sub-module the cell for the "Wing loading" parameter has a white background. That means that it is an input cell (according to general layout rules). In fact it is a result cell, but the value in this cell has to be updated by the user manually. Figure 4.7 shows the situation when the user has to update the value by choosing the latest result form the drop-down list.

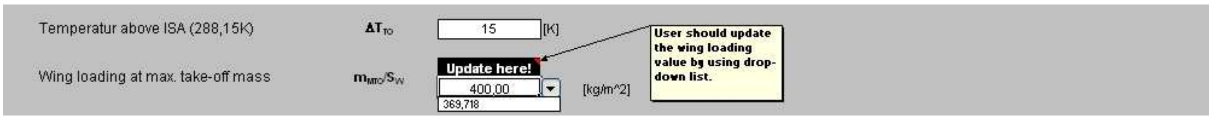

Figure 4.7 Updating the wing loading value

4.2.4 Second segment

In the nomenclature used in **Scholz 2009** the second segment refers to the fight phase between compete landing gear retraction and the flight altitude of 400 ft. For this segment certification regulations require a minimum climb gradient of under one engine inoperative (OEI) condition depending on the total number of engines installed on the aircraft. For a two engines plane climb gradient (sinus of the flight path angle γ) must be not lower than 0.024. The "2nd segment" sub-module comprises of five input parameters (see Figure 4.8).

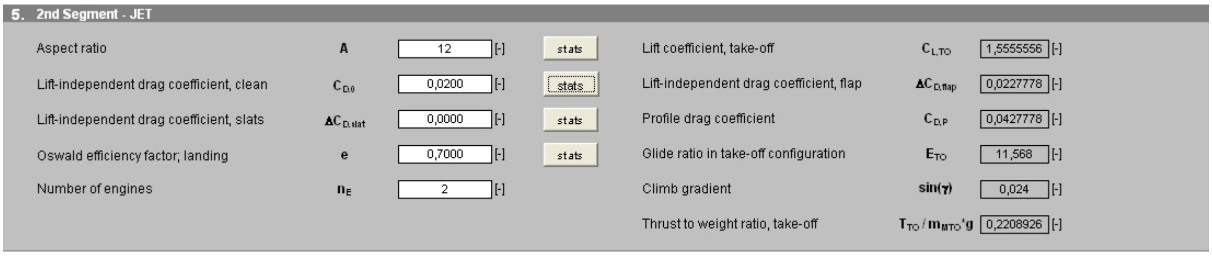

Figure 4.8 2nd Segment

Two of them refer to a drag coefficient. The "Clean lift independent drag coefficient", $C_{D,0}$, and the "Extra drag coefficient due to flaps extension", $\Delta C_{D,flap}$, are components of the "Parasite drag coefficient", $C_{D,p}$. Due to lack of slats mounted on the ATR 72-600 $\Delta C_{D,flap}$ is given as zero. The "Clean lift independent drag coefficient" equals 0.02. The value is taken from statistics, as shown in Figure 4.9.

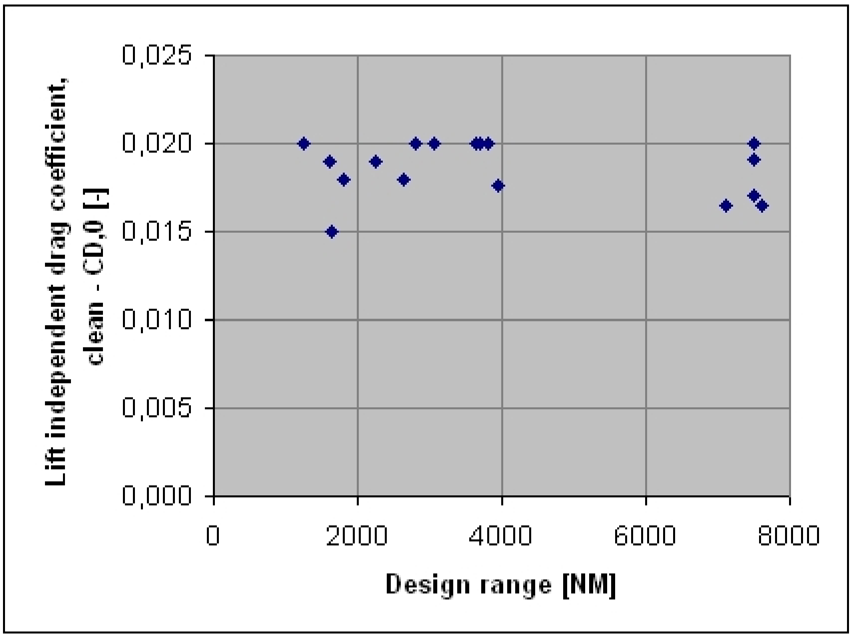

Figure 4.9 $C_{D,0}$ as the function of "Range" (2^{nd} Segment)

The "Aspect ratio", which is given as 12, is a geometrical parameter and it is provided by the manufacturer. Oswald efficiency factor, *e*, during the landing phase is typically estimated as 0.7.

4.2.5 Missed approach

The missed approach requirement is very similar to the second segment requirement. The algorithm employed by the preliminary sizing module of PreSTo is the same as in the 2^{nd} Segment sub-module, only the input values are different. See Figure 4.10.

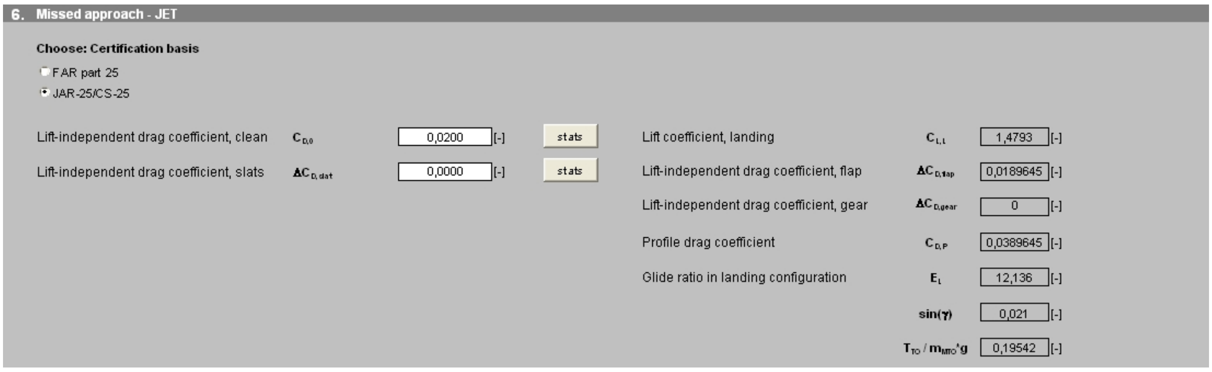

Figure 4.10 Missed approach

Missed approach means that during the process of making the final approach for some reason a crew has to take a decision to abort the landing procedure. Take-off thrust is applied, an aircraft climbs and makes a new approach according to a predefined procedure. The aircraft climbs, although it is still in the landing configuration – with considerable drag: the landing gear has already been extended and the flaps are in landing position. The regulations require sufficient installed thrust to carry out this maneuver in the safe way (**Scholz 2009).** There is a significant difference between European and American certification regulations. According to FAR Part 25 the landing gear is still extended. CS-25 states just the opposite: the landing gear could be already retracted.

As we can see in Figure 4.10 the appropriate "Certification basis" has been chosen. Based on the statistics chart (Figure 4.11) the "Clean lift independent drag coefficient" is estimated as 0.02.

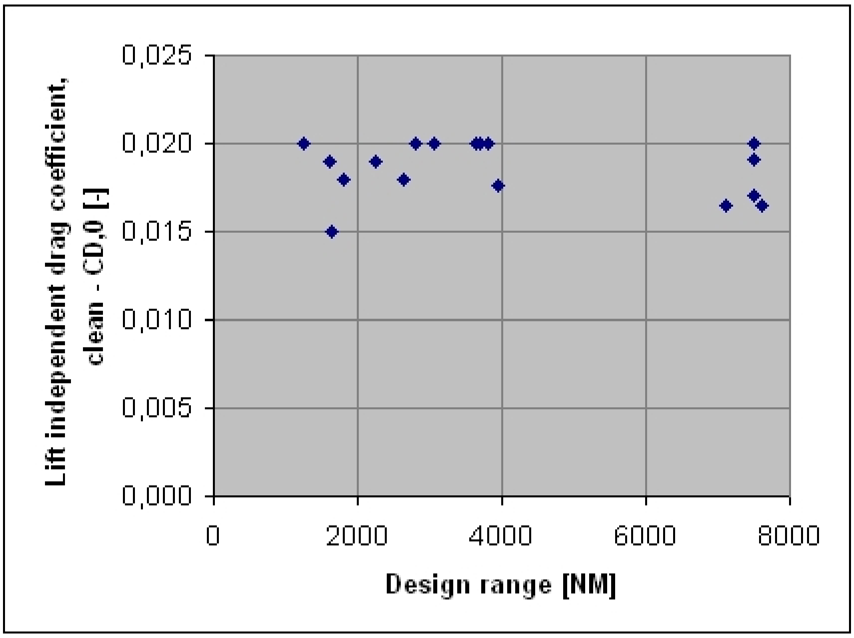

Figure 4.11 $C_{D,0}$ as the function of "Range" (Missed approach)

4.2.6 Cruise flight

For calculations in the cruise phase we assume a stationary straight flight at cruise altitude. From the physical point of view that means that lift is equal to weight and drag is equal to thrust. The performance requirement in cruise flight is that of climb. The reason for this is the definition of the service ceiling. The definition states that when flying at service ceiling, a jet still has to reach a climb of 500 ft/min. For flights at any other, lower altitude, at least the same climb speed is expected.

The "Max. Glide Ratio in Cruise" sub-module includes eight input parameters, as seen in Figure 4.12.

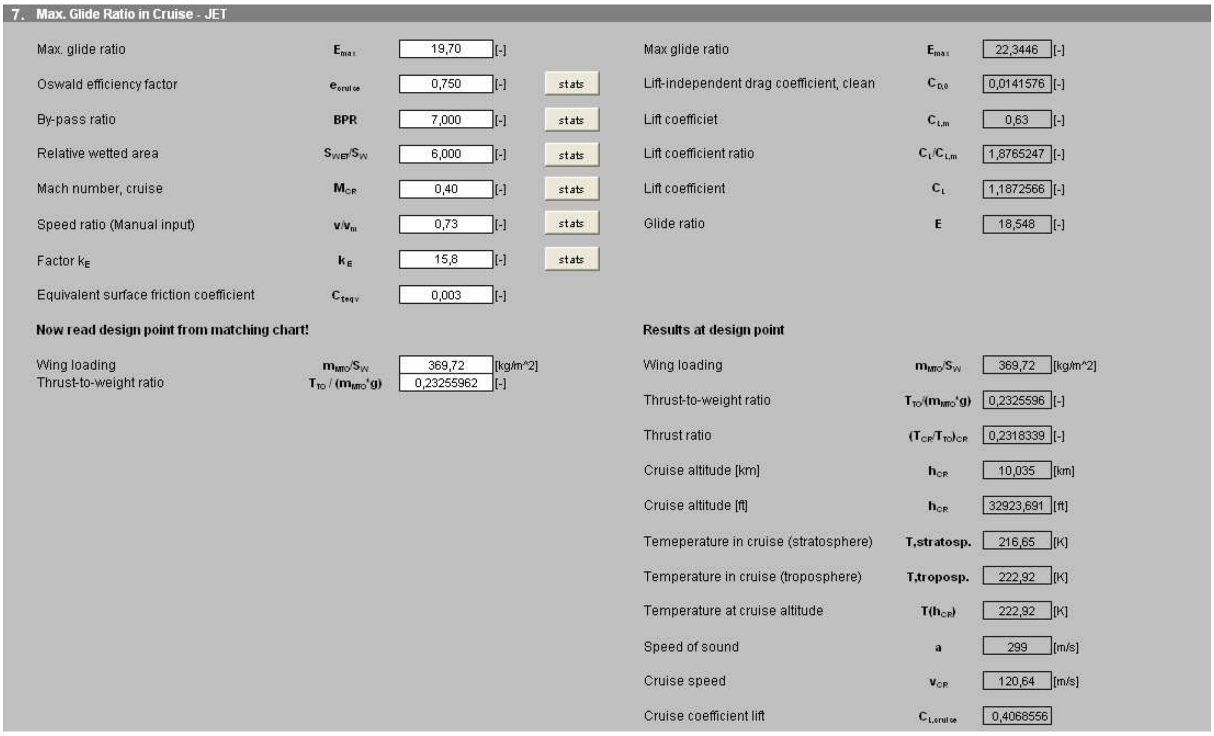

Figure 4.12 Max. Glide Ratio in Cruise

The first input parameter is the "Max. glide ratio", E_{max}, which is basically a ratio of lift force to drag force, $E = \frac{L}{D}$. The lift to drag ratio depends directly on the wing aspect ratio (a higher value for A gives back a higher value for E) and is also affected by the wetted area relative to the wing area, S_{wet}/S_{W}. To derive E_{max} we can use the following formula:

$$E_{\max} = k_E \sqrt{\frac{A}{S_{wet}/S_W}} \tag{4.1}$$

However, we need to estimate the value for k_E factor. We can do this by using the following formula:

$$k_E = \frac{1}{2}\sqrt{\frac{\pi \cdot e}{\bar{c}_{f,eqv}}} \tag{4.2}$$

If we consider the value of e=0.75 for the Oswald factor and the value of $\bar{c}_{f,\mathrm{eqv}}$=0.03 for the friction coefficient, than we derive the value k_E=14.012. However, according to **Raymer 2006** the k_E value can be estimated as 15.8, which seems to be more realistic in case of the ATR 72-600. **Raymer 2006** provides the diagram for the ratio of wetted area to wing area for different aircraft's configurations, as seen in Figure 4.13.

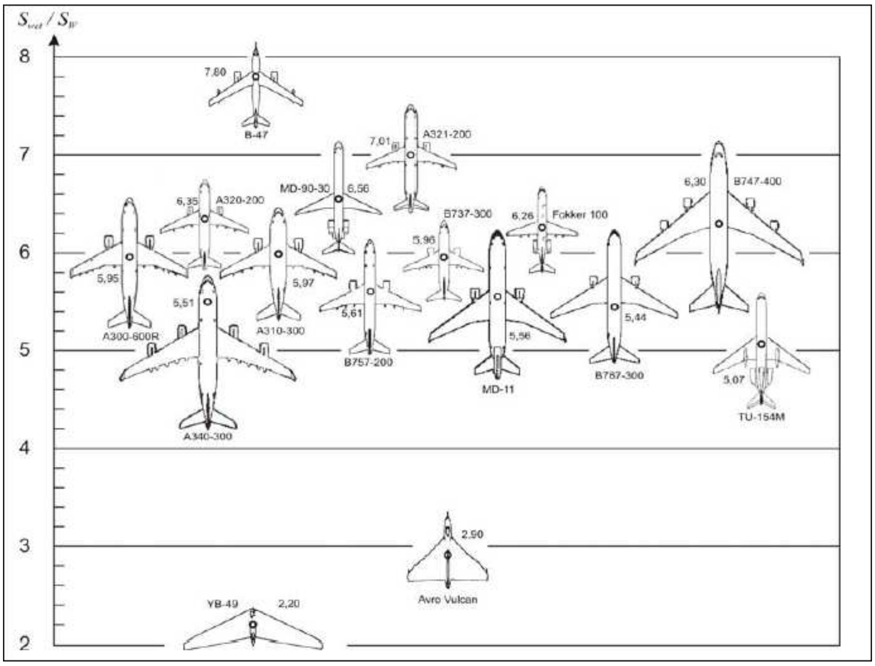

Figure 4.13 Aircraft plan form - relative wetted area S_{wet}/S_w (**Raymer 2006**)

In case of the ATR 72-600 the value of S_{wet}/S_w=6.0 seems to be the most appropriate. For a given k_E, the maximum *L*/*D* becomes: E_{max}=19.64. For further details see **Scholz 2009**.

4.2.7 Matching chart

After filling in all those parameters we can finally read the design point. The "Wing loading" and the "Thrust-to-weight" cells do also need to be updated manually by the user (the example can be seen in Figure 4.7). "Results at the design point", which are basically values that define performances of the aircraft and conditions occurring during the cruise, are placed on the left-hand side of sub-module (see Figure 4.12). The results at the design point are listed in Table 4.2.

Table 4.2 The result at the design point

Measurement	Symbol	Value
Wing loading	m_{MTO}/S_W	369,72 kg/m^2
Thrust-to-weight ratio	$T_{TO}/(m_{MTO}*g)$	0,2325596
Thrust ratio	$(T_{CR}/T_{TO})_{CR}$	0,2318339
Cruise altitude	h_{CR}	10,035 km
Cruise altitude	h_{CR}	32923 ft
Temperature in cruise (stratosphere)	T,stratosp.	216,65 K
Temperature in cruise (troposphere)	T,troposp.	222,92 K
Temperature at cruise altitude	$T(h_{CR})$	222,92 K
Speed of sound	a	299 m/s
Cruise speed	v_{CR}	120,64 m/s
Cruise coefficient lift	$C_{L,cruise}$	0,4068556

The results of previous certification requirements are plotted in the preliminary sizing matching chart to find one single design point (see Figure 4.14). The first priority is to minimize the thrust-to-weight ratio to be able to select or develop the smallest and hence cheaper engines. In second priority one tries to maximize the wing loading, which leads to a smaller, lighter and principally cheaper wing. The results presented in Figure 4.14 are the same as in Table 4.2. The “Wing loading” equals 369.72 kg/m^2 and the “Thrust-to-weight ratio” is given as 0.2325.

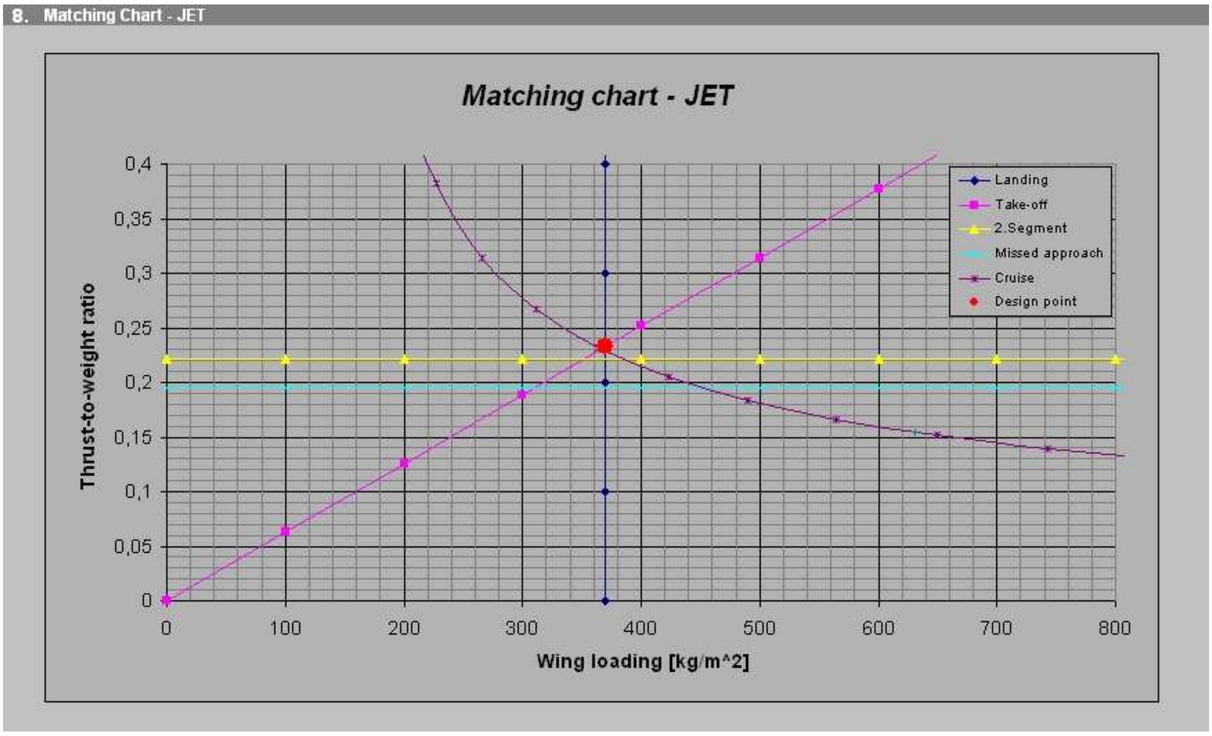

Figure 4.14 Matching chart

4.2.8 Estimation of the aircraft size

After having determined the aircraft design point we have to estimate the number of aircraft masses, required take-off thrust, T_{to}, and amount of fuel needed, m_{mf}, V_{mf}. Aircraft masses to estimate are:

- Operating empty mass, m_{oe},
- Max. zero-fuel mass, m_{mzf},
- Max. take-off mass, m_{mto},
- Max. landing mass, m_{ml}.

After having determined these numbers it is possible to estimate the size of the aircraft, meaning to achieve initial values for in example: wing area etc. Than we can *go ahead* with the conceptual design.

As can be seen in Figure 4.15 the first step[6] – dealing with PreSTo – is to choose an aircraft type in terms of “Range”. The user has two possibilities:

- Short/medium range,
- Long range.

In case of ATR 72-600 “Short/medium range” option should be picked. That determines the “Mass of a passenger”, m_{pax}, parameter as 93 kg.

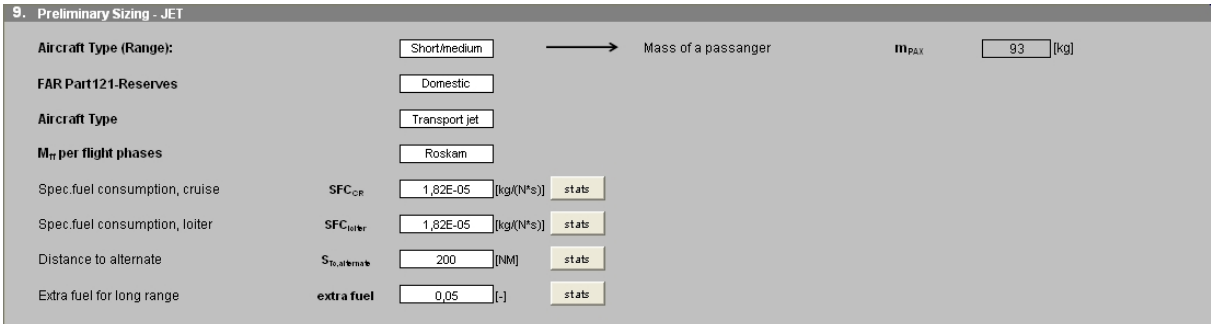

Figure 4.15 Preliminary sizing - part one

4.2.9 Fuel fractions

The next three options (“FAR Part 121 – Reserves”; “Aircraft Type” and “M_{ff} per flight phases”) refer directly to fuel friction values, which can be seen in Figure 4.16. However, before calculating fuel frictions, specific fuel consumption for both cruise and loiter have to be set. If the user does not have an appropriate data, the values should be taken from the statistic module. In case of PW127M engine the manufacturer provides the specific fuel consumption, which is given as 1.82E-5 kg/(N·s).

The “Distance to alternate” and the “Extra fuel for long range” are the parameters concerning two safety aspects, posed on the aircraft by international regulations that state:

- An extra flight distance of 200 NM to an alternate airport in case the originally planned one is closed or not available for any other reason,

[6] Due to the fact that “Preliminary sizing – JET” sub-module of the “Preliminary sizing” module is the biggest sub-module of the spreadsheet, there are four screenshots that depict this part of the application.

- An increase in fuel consumption, expressed as an extra flight distance of 5 % of the original reference mission.

For that reason the “Distance to alternate” and the “Extra fuel for long range” are given as 200 NM and 0.05, respectively.

In Figure 4.16 we can see the next part of the “Preliminary sizing – JET” sub-module which deals with the “Relative operating empty mass”, m_{OE}/m_{mTO}, and the values for fuel fractions during different flight phases.

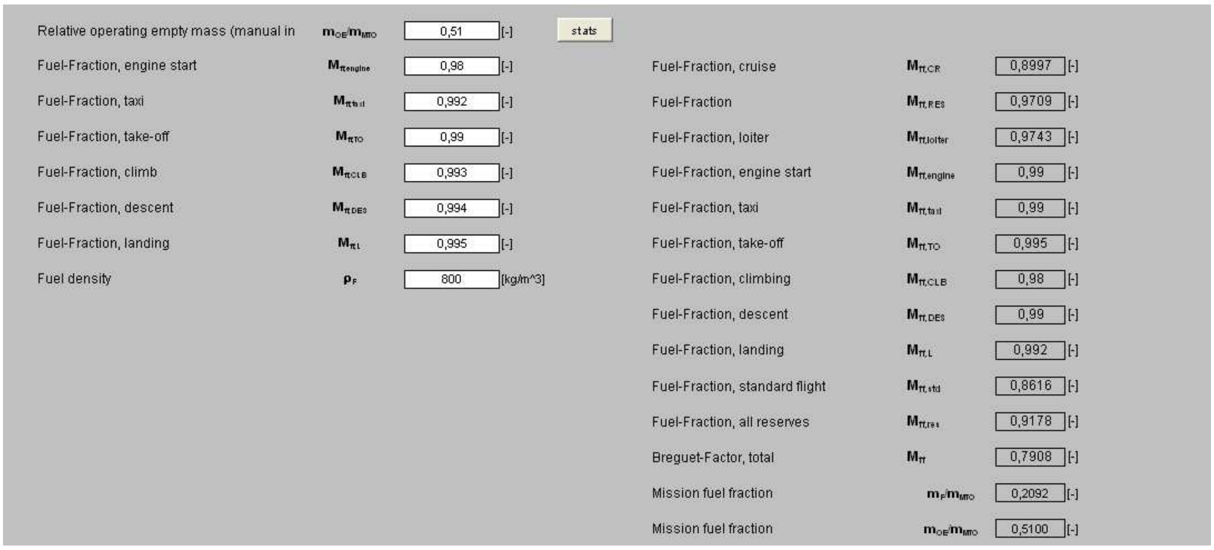

Figure 4.16 Preliminary sizing - part two

The “Relative operating empty mass” can be taken from the statistics, however, in case of ATR 72-600 we are able to calculate it from data provided by the manufacturer. The “Relative operating empty mass” ratio equals 0.51. The user has to know the values for fuel fractions during different flight phases. Example, which is being described, employs the values given by **Roskam 2007**. See Table 4.3.

Table 4.3 Fuel fraction values for different flight phases

Fuel Fraction (flight phase)	Symbol	Value
Engine start	$M_{ff,engine}$	0,98
Taxi	$M_{ff,taxi}$	0,992
Take-off	$M_{ff,TO}$	0,99
Climb	$M_{ff,CLB}$	0,993
Descent	$M_{ff,DES}$	0,994
Landing	$M_{ff,L}$	0,995

The last input parameter it the sub-module is the “Fuel density”, ρ_F. For kerosin, the standard value is given as 800 kg/m^3. On the left-hand side, in Figure 4.16 we can see the results of the fuel fraction calculations.

4.2.10 Results of the estimation

In Figure 4.17 the third part of the "Preliminary Sizing – Jet" sub-module is shown. This part deals with results regarding masses of the aircraft, thrust, wing area as well as needed fuel tank volume and the other "fuel" parameters.

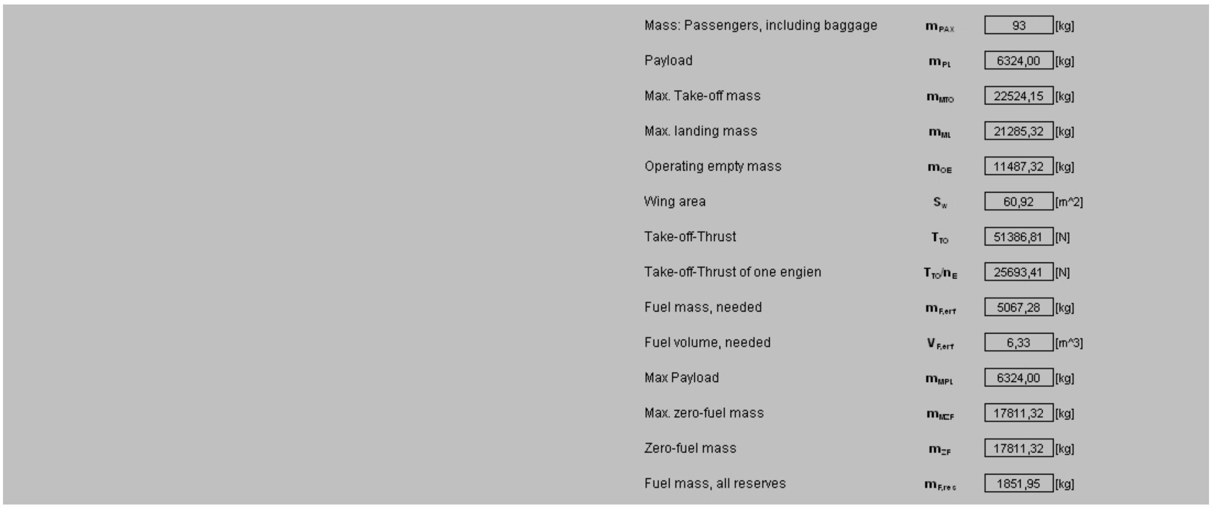

Figure 4.17 Preliminary sizing - part three

These parameters are basically the final parameters which describe the re-designed aircraft (see Table 4.4). With these values, in the next step, the conceptual design of an aircraft can be carried out.

Table 4.4 The final parameters describing the re-designed aircraft

Measurement	Symbol	Value
Mass: Passengers, including baggage	m_{PAX}	93 kg
Payload	m_{PL}	6324 kg
Max. Take-off mass	m_{MTO}	22524 kg
Max. landing mass	m_{ML}	21285 kg
Operating empty mass	m_{OE}	11487 kg
Wing area	S_w	60,92 m^2
Take-off-Thrust	T_{TO}	51386 N
Take-off-Thrust of one engine	T_{TO}/n_E	25693 N
Fuel mass, needed	$m_{F,erf}$	5067 kg
Fuel volume, needed	$V_{F,erf}$	6,33 m^3
Max Payload	m_{MPL}	6324 kg
Max. zero-fuel mass	m_{MZF}	17811 kg
Zero-fuel mass	m_{ZF}	17811 kg
Fuel mass, all reserves	$m_{F,res}$	1851 kg

After having calculated all these parameters, a check concerning the relation of maximum landing mass to maximum zero-fuel mass plus fuel reserves has to be performed. The aircraft must be able to land with maximum zero-fuel mass and none of the reserve fuel being used.

Otherwise, it would be simply not possible to conduct a trouble-free flight if the reserve fuel mass kept the aircraft from landing. The requirement can be written as follow:

$$m_{ml} > m_{zf} + m_{f,res} \tag{4.3}$$

The re-design aircraft fulfills this requirement, as can be seen in Figure 4.18. That means that the preliminary sizing process is completed.

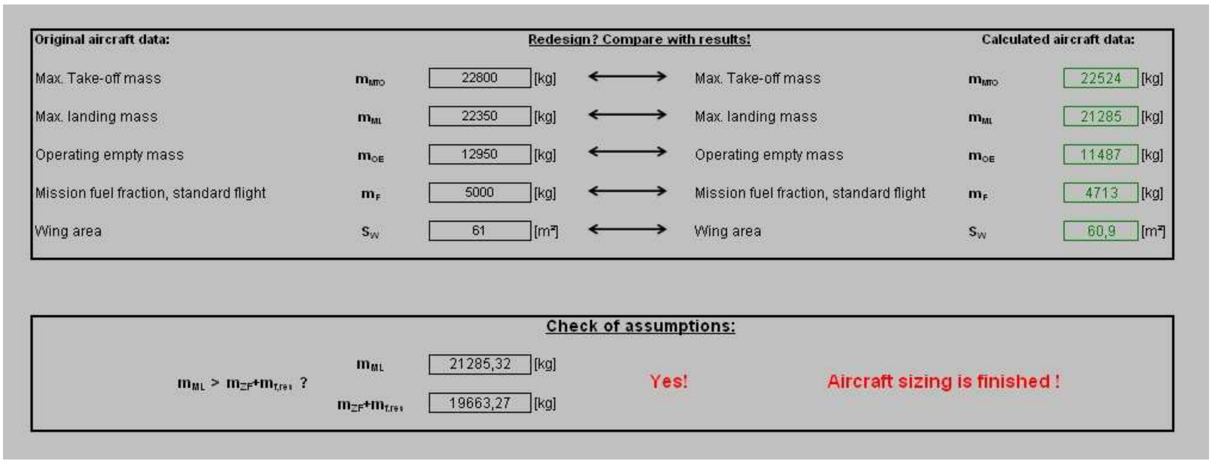

Figure 4.18 Preliminary sizing - part four

As mentioned before, the "Preliminary Sizing – JET" module allows the user to compare the assumed parameters with the results of the re-design process. During the re-design, which is being described as an example, the "Assumption parameters" are basically the data of the ATR 72-600 provided by the manufacturer. The further discussion of the results follows in Section 4.2.

Within the scope of the project the re-design process of the propeller version of the ATR 72-600 was carried out as well. One of the aims of the project was to deliver two "design modes" which are as similar as possible to one another. In fact, the propeller version of the preliminary sizing module of PreSTo differs from the jet one only at some points. The calculations of the "propeller efficiency" seem to the biggest difference. The following sub-modules of the propeller version of the preliminary sizing module include propeller efficiency estimations:

- Take-off
- 2nd Segment
- Missed approach
- Parameter[7].

[7] "Parameter" refers directly to the "Max. Glide in Cruise" sub-module of the propeller mode design.

The “DOC – Direct Operating Costs” sub-module of the propeller design mode is the second significant difference. This sub-module deals with calculations of the entire operating costs of the aircraft. Details regarding DOC methods can be found in **Scholz 2009**. In Figure C.11 (Appendix C) the “DOC – Direct Operating Costs” sub-module can be seen.

The elaborate presentation of features of the propeller version of PreSTo – especially in terms of propeller efficiency - can be found in **Wolf 2009**. **NITA 2008**, on the other hand, provides the detailed description of a re-design process of ATR 72-500 (with standard propulsion system.). The examples presented in abovementioned reports base on the same algorithm which is employed by the current propeller design mode of PreSTo.

The results of the re-design process of the ATR 72-600 carried out by the author of the report are presented as screenshots in Appendix C.

4.3 Discussion of the results

The final *detailed* results are hold by Table 4.4. In order validate the preliminary sizing process the key design results however were compared to the “Assumption parameters”, as we can be seen in Table 4.5 (and in Figure 4.18).

Table 4.5 Results of the re-design in comparison with the reference aircraft data

Measurement	Symbol	Original data	Results
Max. Take-off mass	m_{MTO}	22800 kg	22524 kg
Max. landing mass	m_{ML}	22350 kg	21285 kg
Operating empty mass	m_{OE}	12950 kg	11487 kg
Mission fuel fraction, standard flight	m_F	5000 kg	4713 kg
Wing area	S_W	61 m^2	60,9 m^2

All the result values presented in Table 4.5 are lower then the values provided by the manufacturer of the ATR 72-600. Basically, if the results of the preliminary sizing process do not exceed the “Assumption parameters” the user can state that the re-design process is a successful one. On the other hand if they are to low and they do not correspond closely to appropriate original values there could be a risk of an error. In such a case the preliminary sizing process should be revised or even carried out again form the beginning.

The “Max. Take-off mass” value, given by ATR, is 22800 kg, whereas the result value is given as 22524 kg. This is the smaller difference (276 kg) in terms of the presented masses. The biggest one is between the original and calculated maximum landing mass and it is given as 1463 kg. The “Mission fuel fraction for standard flight” parameter is lower than given by the manufacturer (the difference is 287 kg). The reason for that could be for example too optimistic value of Specific Fuel Consumption provided by the manufacturer of the engine.

The “Wing area” calculated value is nearly the same as the original one. The difference is 0.1 m^2.

The final results of the re-design of the ATR 72-600 are acceptably accurate for the first iteration loop for which PreSTo is intended to be used for. Regarding the comparison presented above, the key data of the reference aircraft have been met.

Summary

In this report the results of combination of two previously developed preliminary sizing modules of the HAW's Aircraft Preliminary Sizing Tool PreSTo have been described in detail. Furthermore the process of creating the new "CEASIOM input file" module as well as the example of the re-design of the ATR 72-600 (jet and propeller versions) have been presented.

Combination of "jet" and "propeller" preliminary sizing modules was intended to provide the convenient to use and reliable application. The purpose of combination was also to improve and extend the tool. For that reason the new layout rules have been applied. During the developing phase the author of the report followed also the previously defined rules which originate in the "look and feel" philosophy. The process of combination involved the integration of the number of macros. However, in order to enhance the performances of the application the new macros were developed as well.

To facilitate the further development of PreSTo three kinds of templates have been established. The chart template deals with the layout of all the graphs which have been created in the "Preliminary sizing", the "CEASIOM input file" and the "Statistics" modules. The template for the structure of the macros' code has been established to standardize the way the macros are created with. Finally, the template which deals with the general layout of the application has been adopted as well.

The new "CEASIOM input file" module has been described in detail. The user interface as well as the structure of the CEASIOM input file have been presented. The report includes the description of the macro which creates the separated MS-Excel file with the full input code. The reader has been introduced to the way they should follow in order to crate the .xml file. To give the reader the impression of how to deal with the input parameters – which are not provided automatically – the examples of some of them have been presented.

Within the scope of the project the re-design process of the ATR 72-600 (jet and propeller versions) has been carried out. During the re-design the new version of PreSTo has been applied. The report gives the elaborate description of the preliminary sizing process of the jet version of the ATR 72-600.

The first step within the re-design process was to determine the so-called aircraft design point in terms of thrust-to-weight ratio and wing loading. The five initial requirements "landing distance", "take-off distance", "second segment", "missed approach" and "cruise flight" posed to the reference aircraft were examined step by step in order to calculate the aircraft design point. The second step was to estimate basic aircraft parameters like aircraft masses

(maximum take-off, operating empty, etc.), the wing area and the required fuel volume from the determined design point. The results of the re-design have been discussed.

The differences between the jet and the propeller version of the new preliminary sizing module have been described and discussed.

During work on the project the further development steps were recognized by the author of the report as follows. The extension of the “CEASIOM input file” in terms of automatically provided input parameters should be of the primary concern. The new features of already existing modules of PreSTo should be developed in order to provide more data which could “supply” the “CEASIOM input file” module. Also the “Statistics” module should be extended in terms of missing references.

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Appendix A – The main macros' source code

<u>Source code of *ActivateJetMode*:</u>

```
Private Sub ActivateJetMode_Click()

'*****************************************************************************
'
' ActivateJetMode
'
' Activates the jet mode of the preliminary sizing module and deactivate
' both proppeler and compare mode
'
' Author:  Marcin Lenarczyk, Warsaw University of Technology
' Contact: Hamburg University of Applied Sciences, AERO Group
'*****************************************************************************

' Hiding of "propeller rows"

   Application.Goto Reference:="area_0p, area_2p, area_3p, area_4p"        '<<< area_#p is name of a
   Selection.RowHeight = 0                                                  '<<< particular set of cells
   Application.Goto Reference:="area_7p, area_8p, area_5p, area_6p"
   Selection.RowHeight = 0
   Application.Goto Reference:="area_9p, mat_chart_prop, area_10p, area_11p"
   Selection.RowHeight = 0

' Unhiding of "jet rows"

   Application.Goto Reference:="area_0j,area_2j, area_3j, area_4j, area_5j, area_6j"
   Selection.RowHeight = 14.25
   Application.Goto Reference:="area_7j, mat_chart_jet, area_8j"
   Selection.RowHeight = 14.25

   ThisWorkbook.Sheets("preliminary sizing").Range("B4").Select

   ActiveSheet.Outline.ShowLevels RowLevels:=1

' Formating of the title of sub-module

   Range("A2").Select
   With Selection
      .Font.ColorIndex = 2
      .Font.Bold = True
   End With

   Range("B2").Select
   With Selection
      .Font.ColorIndex = 2
      .Font.Bold = True
```

```
    .FormulaR1C1 = "General preliminary sizing data - JET"                    '<<< sub-module title
  End With

  Range("B4").Select

End Sub
```

Source code of *ActivatePropMode*:

```
Private Sub ActivatePropMode_Click()

'*******************************************************************************
'
' ActivatePropMode
'
' Activates the propeller mode of the preliminary sizing module and deactivate
' both jet and compare mode
'
' Author:  Marcin Lenarczyk, Warsaw University of Technology
' Contact: Hamburg University of Applied Sciences, AERO Group
'*******************************************************************************

' Hiding of "jet rows"

  ActiveSheet.Outline.ShowLevels RowLevels:=1
  Application.Goto Reference:="area_0j, area_2j, area_3j, area_4j, area_5j"
  Selection.RowHeight = 0
  Application.Goto Reference:="area_6j, area_7j, mat_chart_jet, area_8j"
  Selection.RowHeight = 0

' Unhiding of "propeller rows"

  Application.Goto Reference:="area_0p, area_2p, area_3p, area_4p, area_5p"
  Selection.RowHeight = 14.25
  Application.Goto Reference:="area_6p, area_7p, area_8p, area_9p"
  Selection.RowHeight = 14.25
  Application.Goto Reference:="mat_chart_prop, area_10p, area_11p"
  Selection.RowHeight = 14.25

' Formating of the title of sub-module

  ActiveSheet.Outline.ShowLevels RowLevels:=1

  Range("A2").Select
  With Selection
    .Font.ColorIndex = 1
    .Font.Bold = True
  End With
```

```
   Range("B2").Select
   With Selection
      .Font.ColorIndex = 1
      .Font.Bold = True
   .FormulaR1C1 = "General preliminary sizing data - PROPELLER"
   End With

   Range("B4").Select

End Sub
```

Source code of *ActivateCompareMode*:

```
Private Sub ActivateCompareMode_Click()

'******************************************************************************
'
' ActivateCompareMode
'
' Activates the propeller and jet mode at the same time
'
' Author:  Marcin Lenarczyk, Warsaw University of Technology
' Contact: Hamburg University of Applied Sciences, AERO Group
'******************************************************************************

' Unhiding of "jet and propeller rows"

   ActiveSheet.Outline.ShowLevels RowLevels:=1
   Application.Goto Reference:="area_0j, area_2j, area_3j, area_4j, area_5j"
   Selection.RowHeight = 14.25
   Application.Goto Reference:="area_6j, area_7j, mat_chart_jet, area_8j"
   Selection.RowHeight = 14.25
   Application.Goto Reference:="area_0p, area_2p, area_3p, area_4p, area_5p"
   Selection.RowHeight = 14.25
   Application.Goto Reference:="area_6p, area_7p, area_8p, area_9p"
   Selection.RowHeight = 14.25
   Application.Goto Reference:="mat_chart_prop, area_10p, area_11p"
   Selection.RowHeight = 14.25

' Formating of the title of sub-module

   ActiveSheet.Outline.ShowLevels RowLevels:=1

   Range("A2").Select
   With Selection
      .Font.ColorIndex = 6
      .Font.Bold = True
   End With
```

```
    Range("B2").Select
    With Selection
        .Font.ColorIndex = 6
        .Font.Bold = True
        .FormulaR1C1 = "General preliminary sizing data - C O M P A R I S O N    M O D E"
    End With

    Range("B4").Select
End Sub
```

Source code of *stat*:

```
Private Sub stat4_Click()

'*******************************************************************************
'
' stat4
'
' The macro provides statistic data for "factor app" (Approach - JET).
' The macro activates the "statistics_jet" spreadsheet
'
' Author:  Sebastian Wolf, Hamburg University of Applied Science
' Update:  Marcin Lenarczyk, Warsaw University of Technology
' Contact: Hamburg University of Applied Sciences, AERO Group
'*******************************************************************************

' Activation of the "statistics_jet" spreadsheet

    With ThisWorkbook.Sheets("statistics_jet")
        .Activate
        .Columns("E:E").Select
        ExecuteExcel4Macro "SHOW.DETAIL(2,5,TRUE)"
        .Columns("K:K").Select
        ExecuteExcel4Macro "SHOW.DETAIL(2,11,TRUE)"
        Application.Goto Reference:=Worksheets("statistics_jet").Range("k1"), Scroll:=True
    End With

' Crating of the chart

    ActiveSheet.ChartObjects(1).Activate
    With ActiveChart
        .ChartArea.Select
        .ChartType = xlXYScatter
        .SeriesCollection.NewSeries
        .SeriesCollection(1).Name = ""
        .SeriesCollection(1).XValues = Worksheets("statistics_jet").Range("F5:F100")
        .SeriesCollection(1).Values = Worksheets("statistics_jet").Range("L5:L100")
        .Axes(xlCategory, xlPrimary).HasTitle = True
```

```
      .Axes(xlCategory, xlPrimary).AxisTitle.Characters.Text = Worksheets("statistics_jet").Range("F2")
      .Axes(xlValue, xlPrimary).HasTitle = True
      .Axes(xlValue, xlPrimary).AxisTitle.Characters.Text = Worksheets("statistics_jet").Range("L2")
    End With

' Chart template implementation

' x - axis format

    With ActiveChart.Axes(xlCategory)
  .HasMajorGridlines = True
  With .MajorGridlines.Border
    .ColorIndex = 16
    .Weight = xlThin
    .LineStyle = xlContinuous
  End With

  .HasMinorGridlines = False
  With .TickLabels.Font
    .Italic = False
    .Size = 12
    .ColorIndex = automatic
  End With
  With .Border
    .ColorIndex = 1
    .Weight = xlThin
    .LineStyle = xlContinuous
  End With
  .MajorTickMark = xlThin
  .MajorTickMark = xlOutside
  .MinorTickMark = xlNone
  .TickLabelPosition = xlLow
  .TickLabels.NumberFormat = "0"
  .MinimumScaleIsAuto = True
  .MaximumScaleIsAuto = True
  .MinorUnitIsAuto = True
  .MajorUnitIsAuto = True
  .Crosses = xlCustom
  .CrossesAt = 0
End With

'y-axis format

With ActiveChart.Axes(xlValue)
  .HasMajorGridlines = True
  With .MajorGridlines.Border
    .ColorIndex = 16
    .Weight = xlThin
    .LineStyle = xlContinuous
  End With
  .HasMinorGridlines = False
```

```
  With .TickLabels.Font
    .Italic = False
    .Size = 12
    .ColorIndex = automatic
  End With
  With .Border
    .ColorIndex = 1
    .Weight = xlThin
    .LineStyle = xlContinuous
  End With
    .MajorTickMark = xlThin
    .MajorTickMark = xlOutside
    .MinorTickMark = xlNone
    .TickLabelPosition = xlHigh
    .TickLabels.NumberFormat = "0"
    .MinimumScaleIsAuto = True
    .MaximumScaleIsAuto = True

    .MajorUnitIsAuto = True
    .MinorUnitIsAuto = True
    .Crosses = xlCustom
    .CrossesAt = 0
End With

 ActiveChart.SeriesCollection(1).Select

    With Selection
        .MarkerBackgroundColorIndex = 1
        .MarkerForegroundColorIndex = 1
        .MarkerStyle = xlDiamond
        .Smooth = True
        .MarkerSize = 5
        .Shadow = False
    End With

    ActiveChart.PlotArea.Select

    With Selection.Interior
        .ColorIndex = 15
        .PatternColorIndex = 2
        .Pattern = xlSolid
    End With

' End of chart template implementation

    With ActiveChart.Axes(xlValue)
        .TickLabels.NumberFormat = "0.00"
    End With

    ThisWorkbook.Sheets("statistics_jet").Range("K5").Select
End Sub
```

Appendix B – The "statistics" macro's source code

The source code of the "create_input_file" macro which is employed by the "CEASIOM input file" module of PreSTo.

```
Sub create_input_file()
'************************************************************************
'
' create_input_file
'
' The macro creates CEASIOM input file, as a new MS-Excel spreadsheet.
'
'
' Author:  Marcin Lenarczyk, Warsaw University of Technology
' Contact: Hamburg University of Applied Sciences, AERO Group
'************************************************************************

' Selecting of cells which contain source code & creating a new MS-Excel fiel

   ActiveSheet.Outline.ShowLevels RowLevels:=2
   Columns("E:L").Select
   Selection.Copy
   Workbooks.Add
   Selection.PasteSpecial Paste:=xlPasteValuesAndNumberFormats, Operation:= _
      xlNone, SkipBlanks:=False, Transpose:=False
   Range("A1").Select
   Application.CutCopyMode = False
   Windows("PreSTo 2.0.xls").Activate
   Range("B3").Select
   ActiveSheet.Outline.ShowLevels RowLevels:=1

   MsgBox "CEASIOM input file has been created. See MS-Excel window ""CEASIOM INPUT"" on the
                              right-hand side"

   MsgBox "Save the ""CEASIOM INPUT"" MS-Excel file as .xml file"


End Sub
```

Appendix C – Screenshots of the "propeller" version of the preliminary sizing module

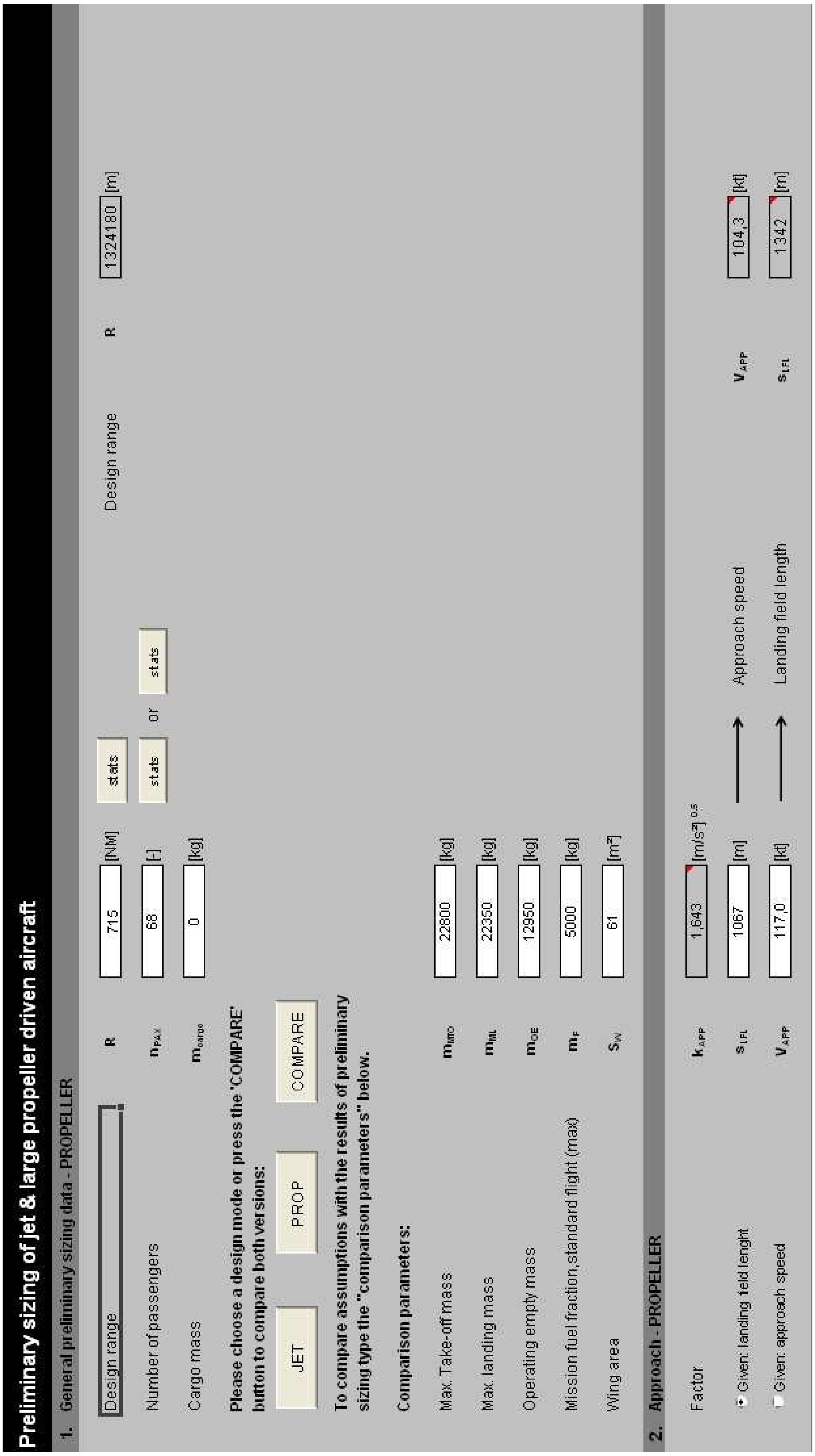

Figure C.1 "General preliminary sizing data" and "Approach" sub-modules

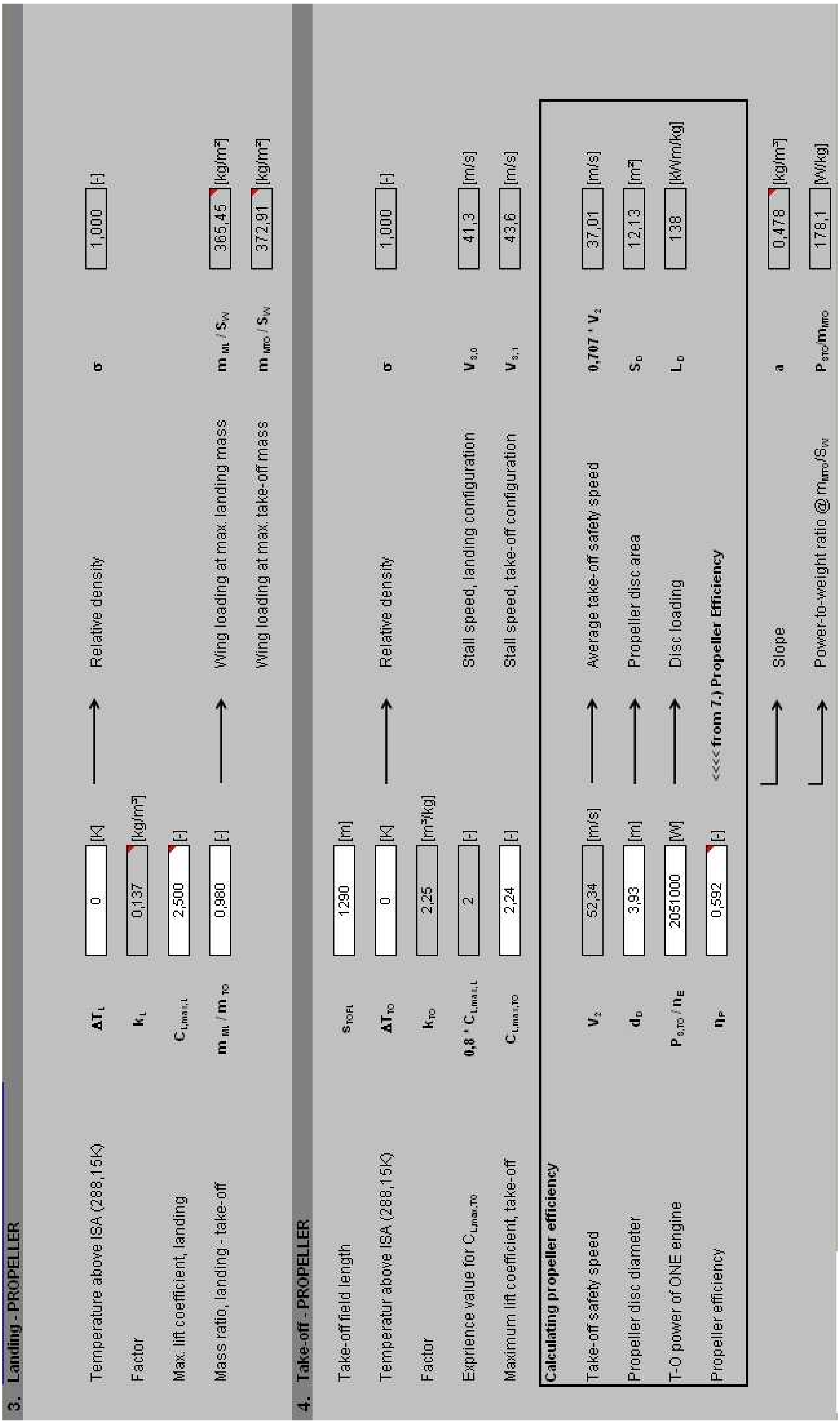

Figure C.2 “Landing” and “Take-off” sub-modules

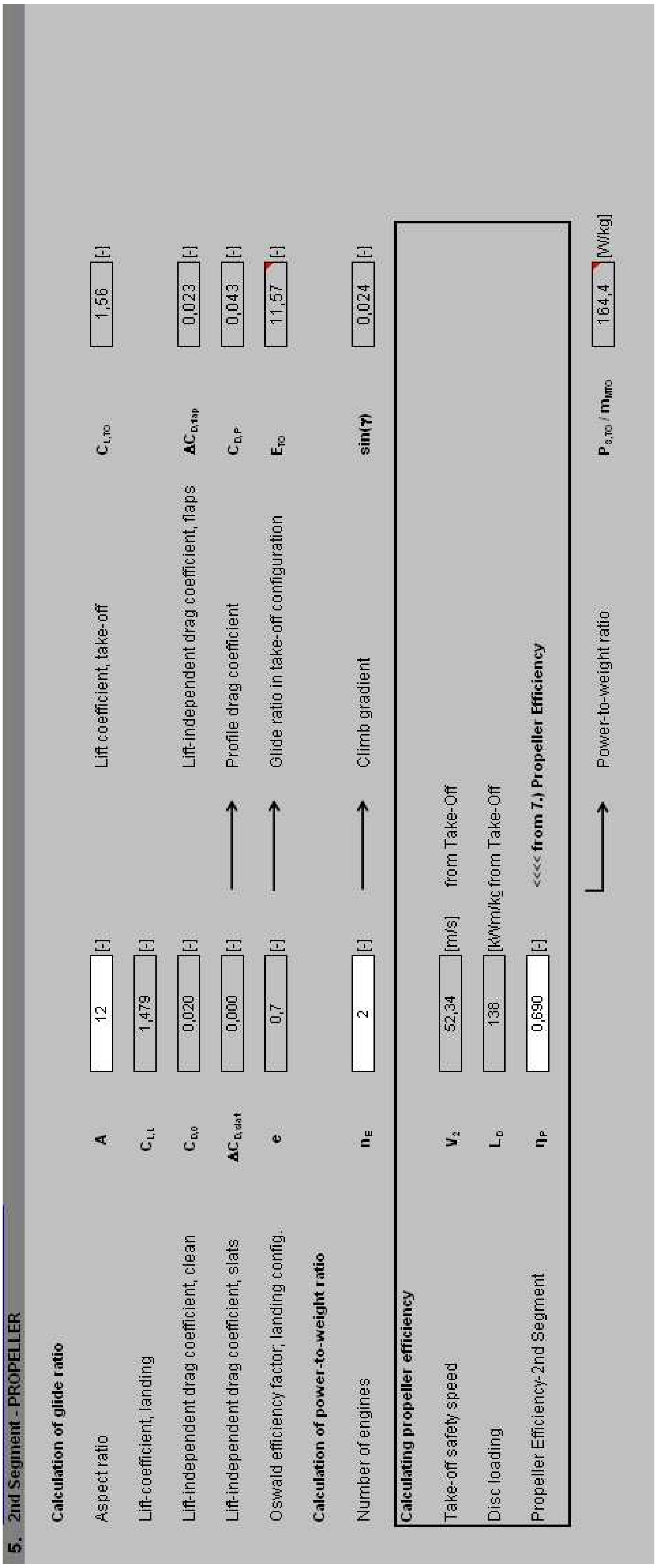

Figure C.3 “2nd Segment” sub-module

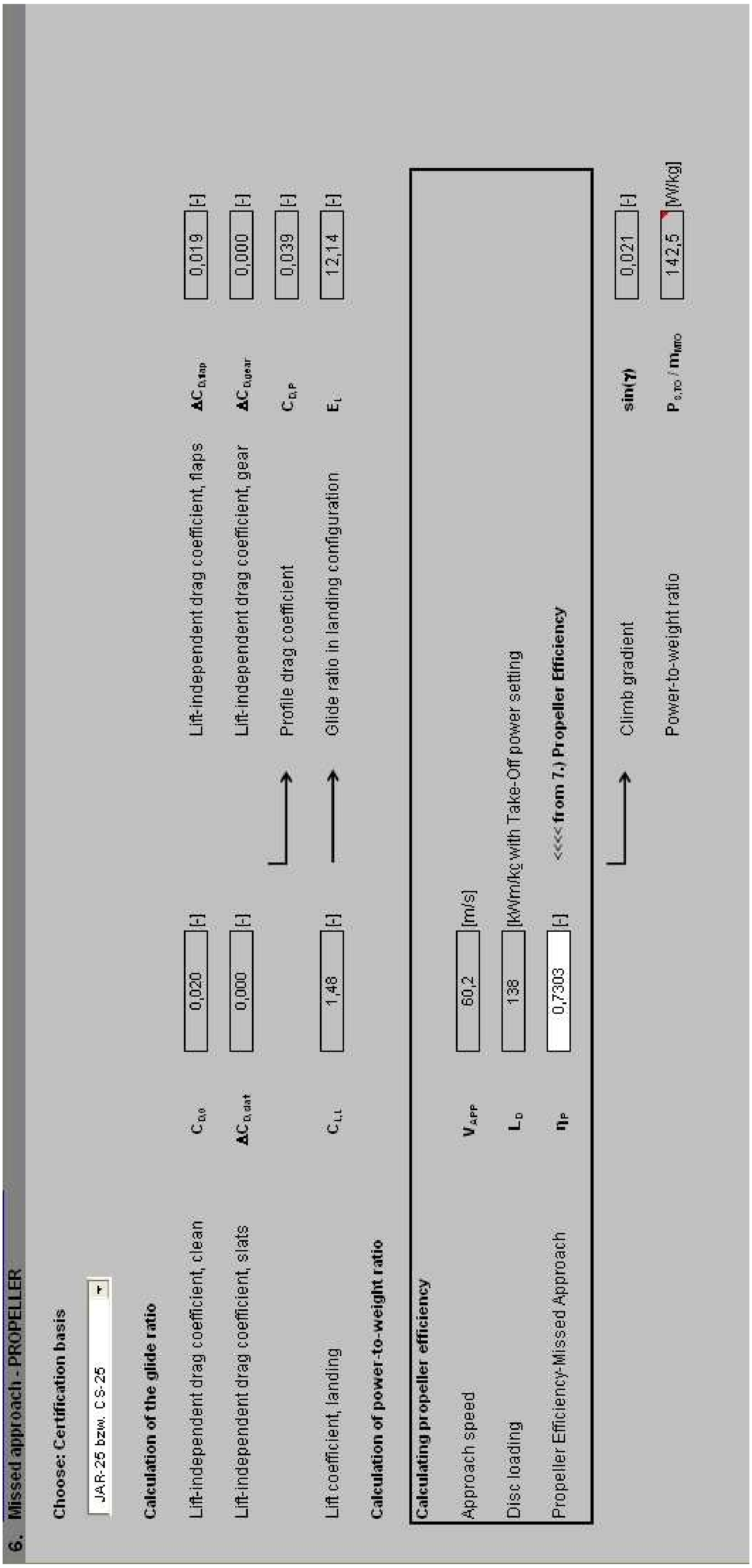

Figure C.4 “Missed-approach” sub-module

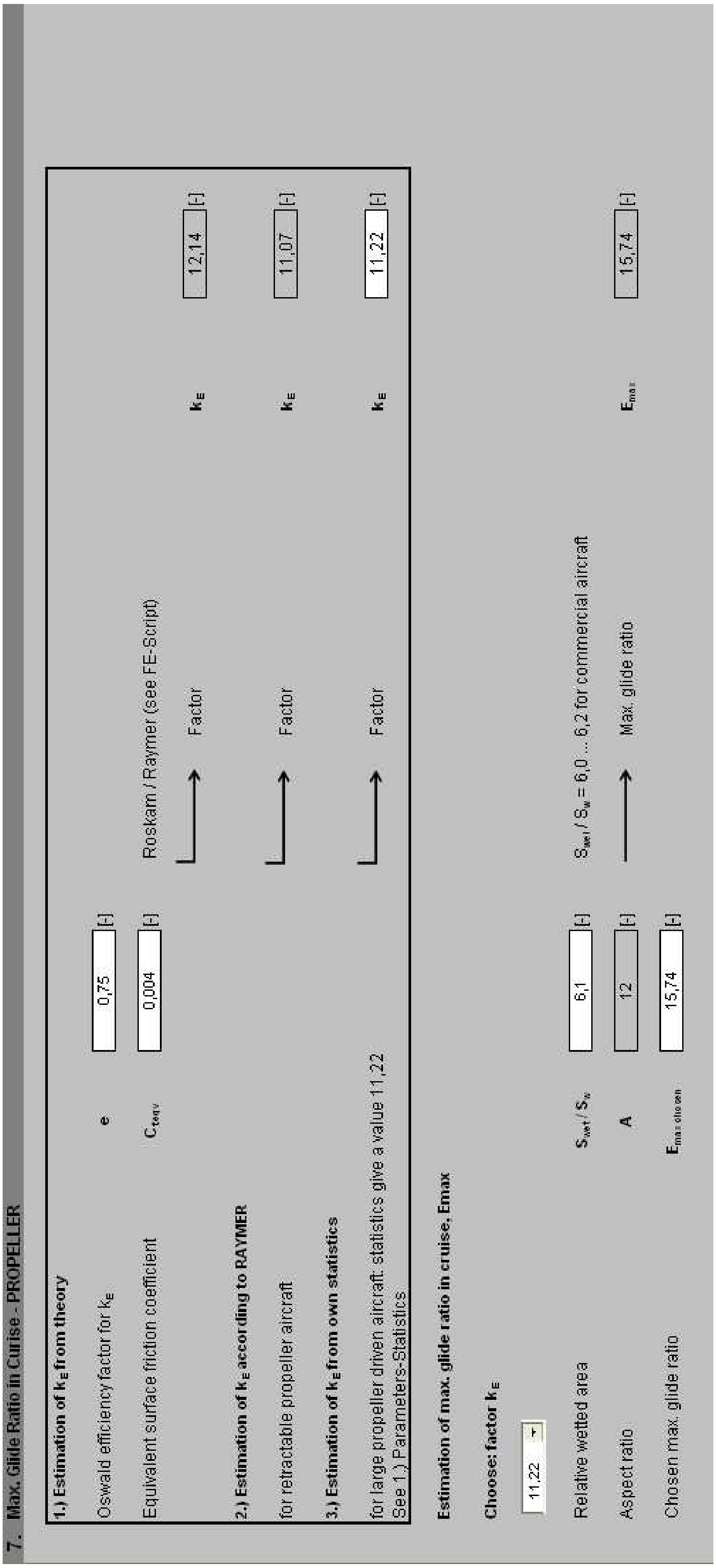

Figure C.5 “Max. Glide Ratio in Cruise” sub-module

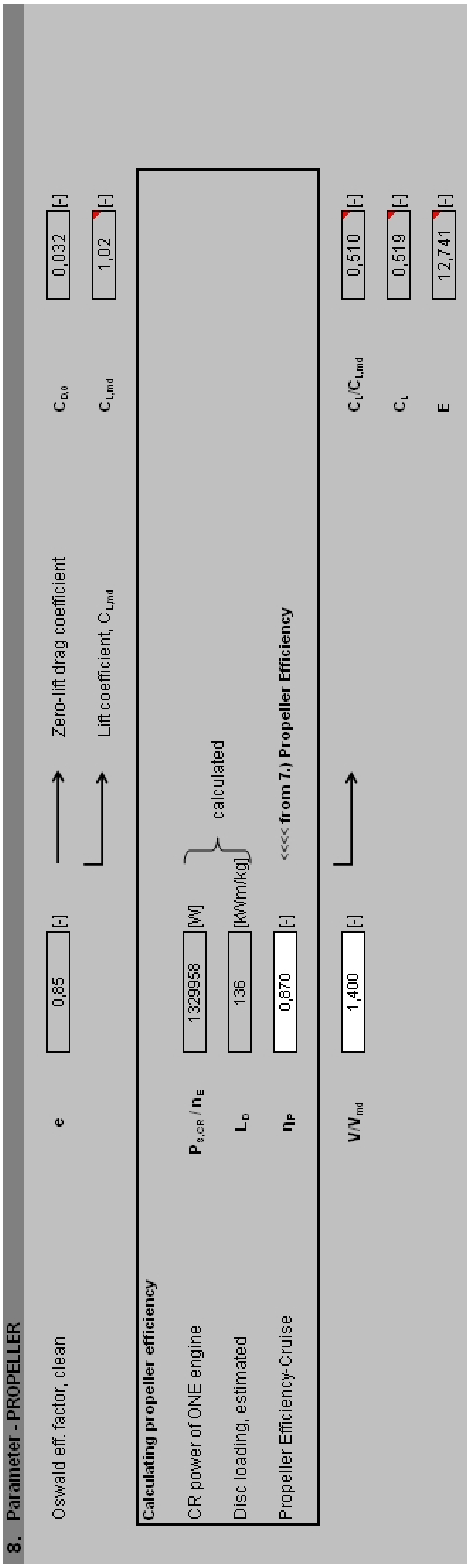

Figure C.6 “Parameter” sub-module

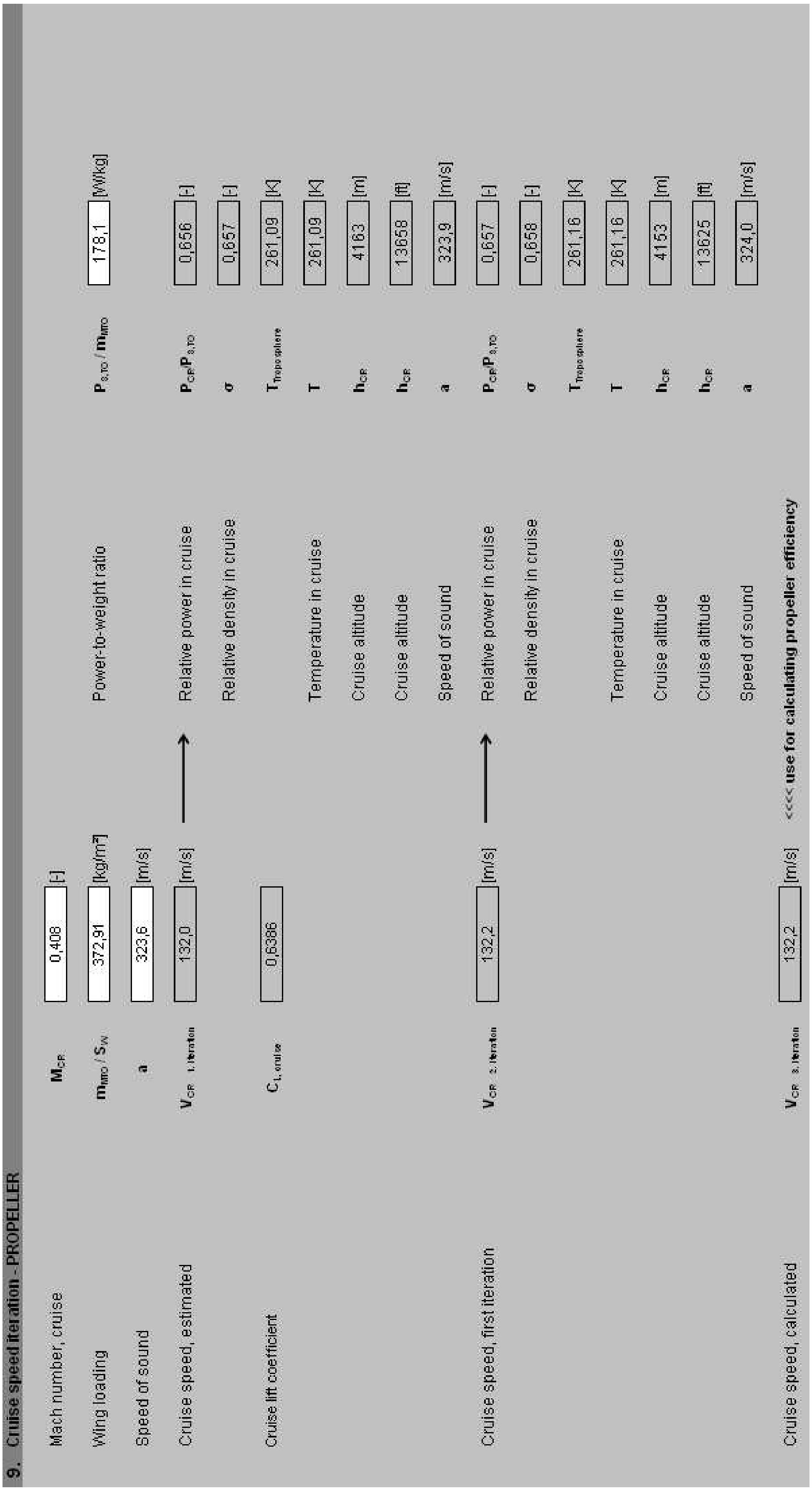

Figure C.7 “Cruise speed iteration” sub-module

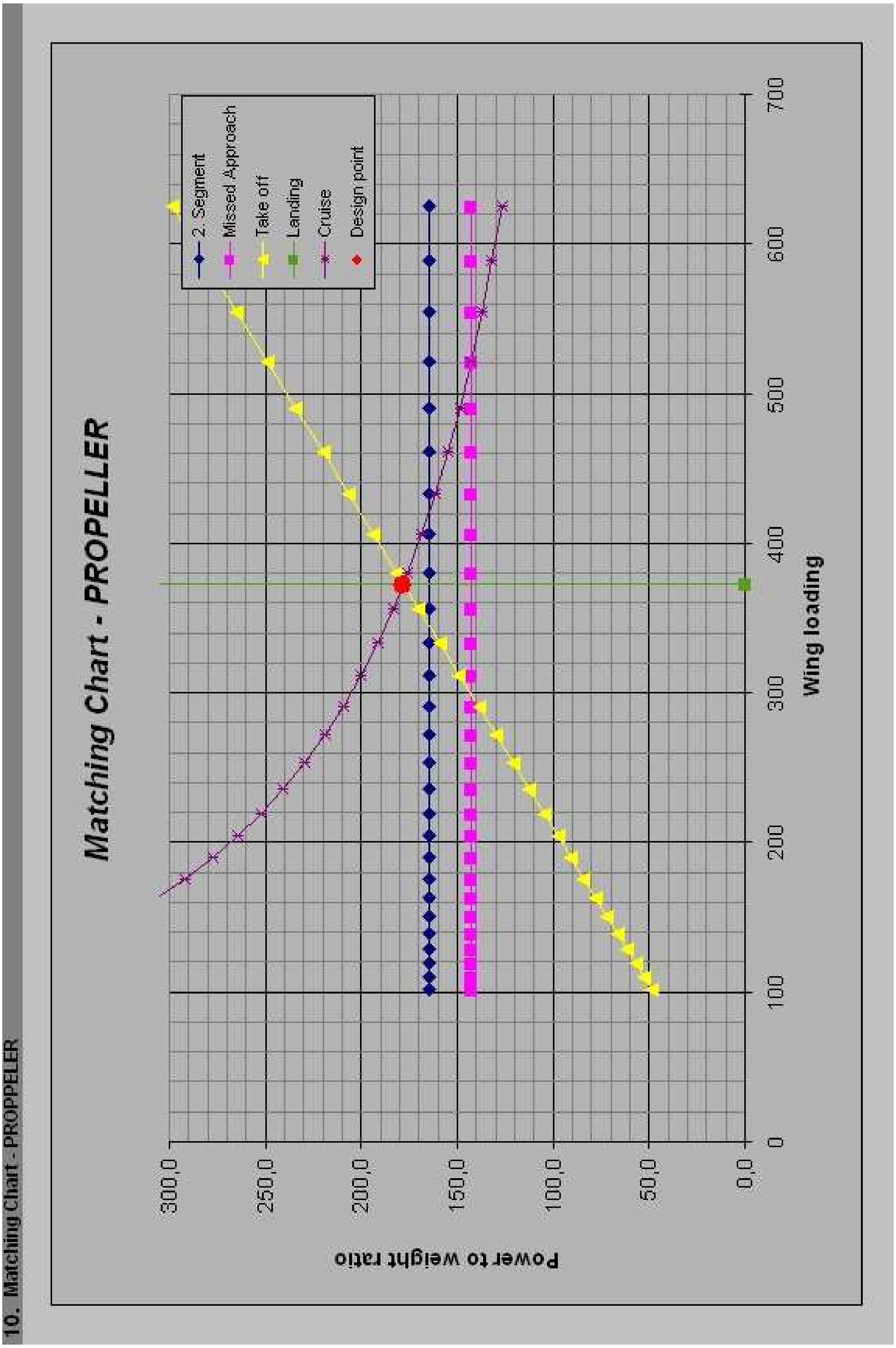

Figure C.8 “Matching Chart” sub-module

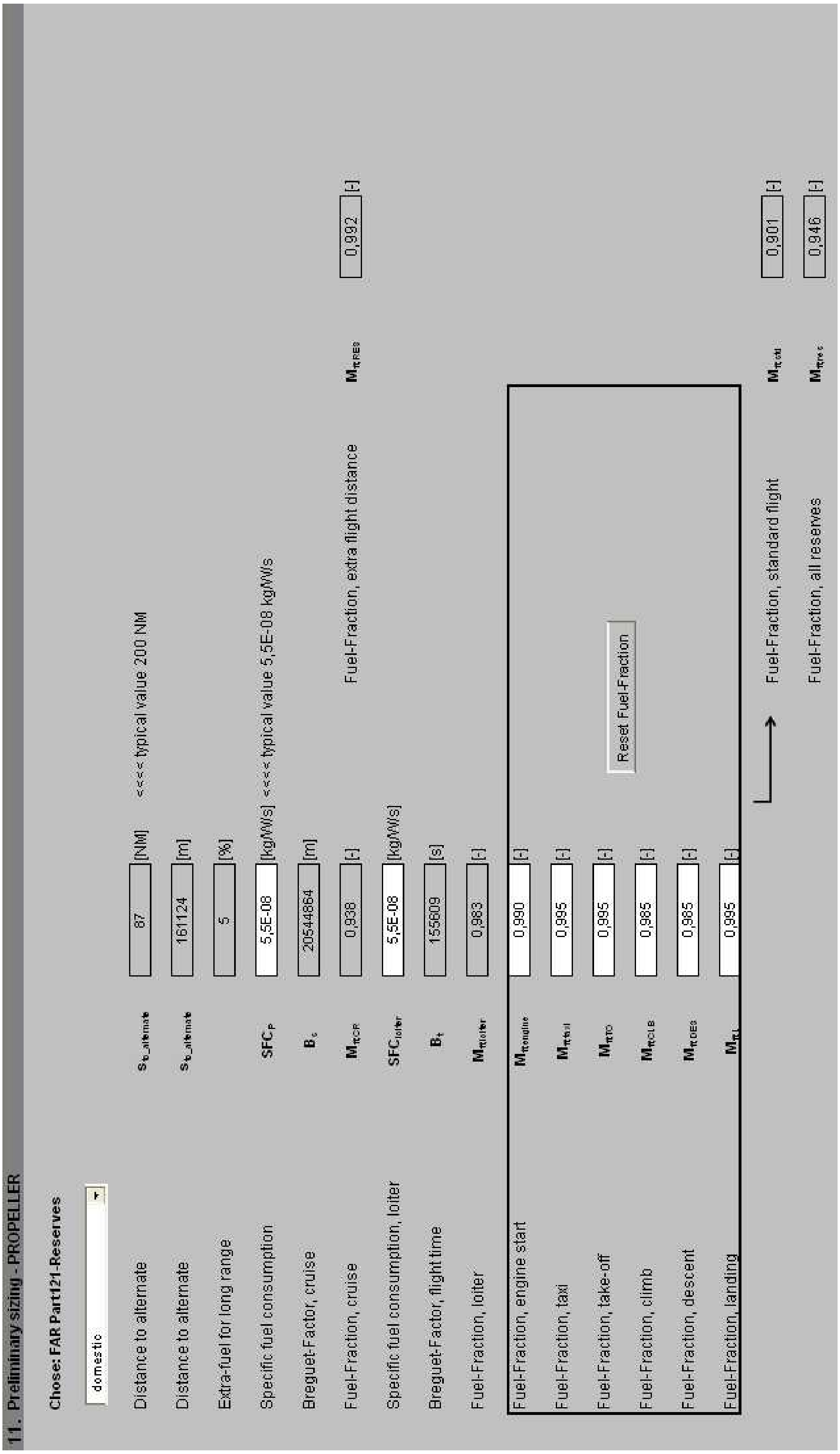

Figure C.9 “Preliminary sizing” sub-module - part 1.

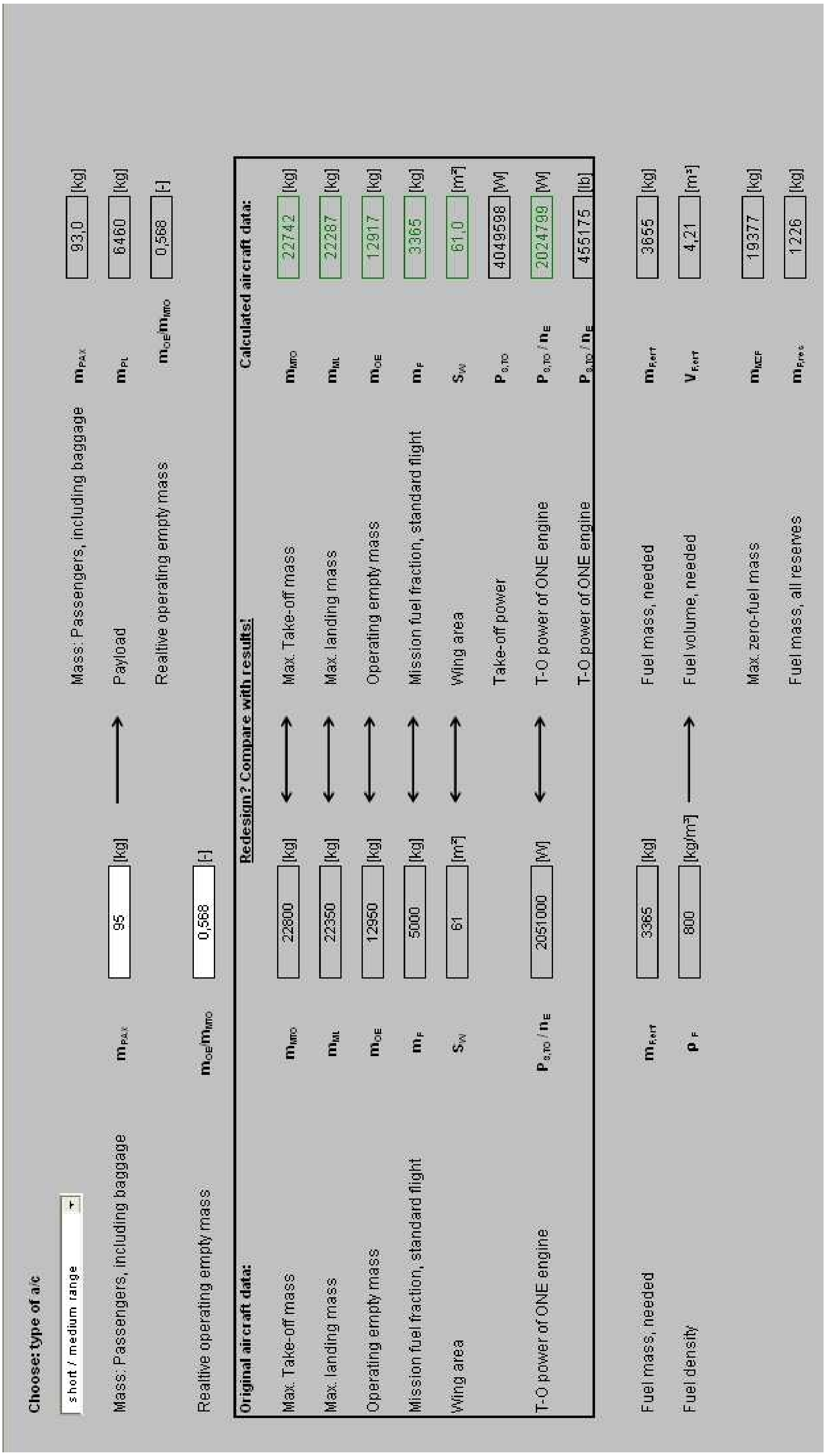

Figure C.10 “Preliminary sizing” sub-module - part 2

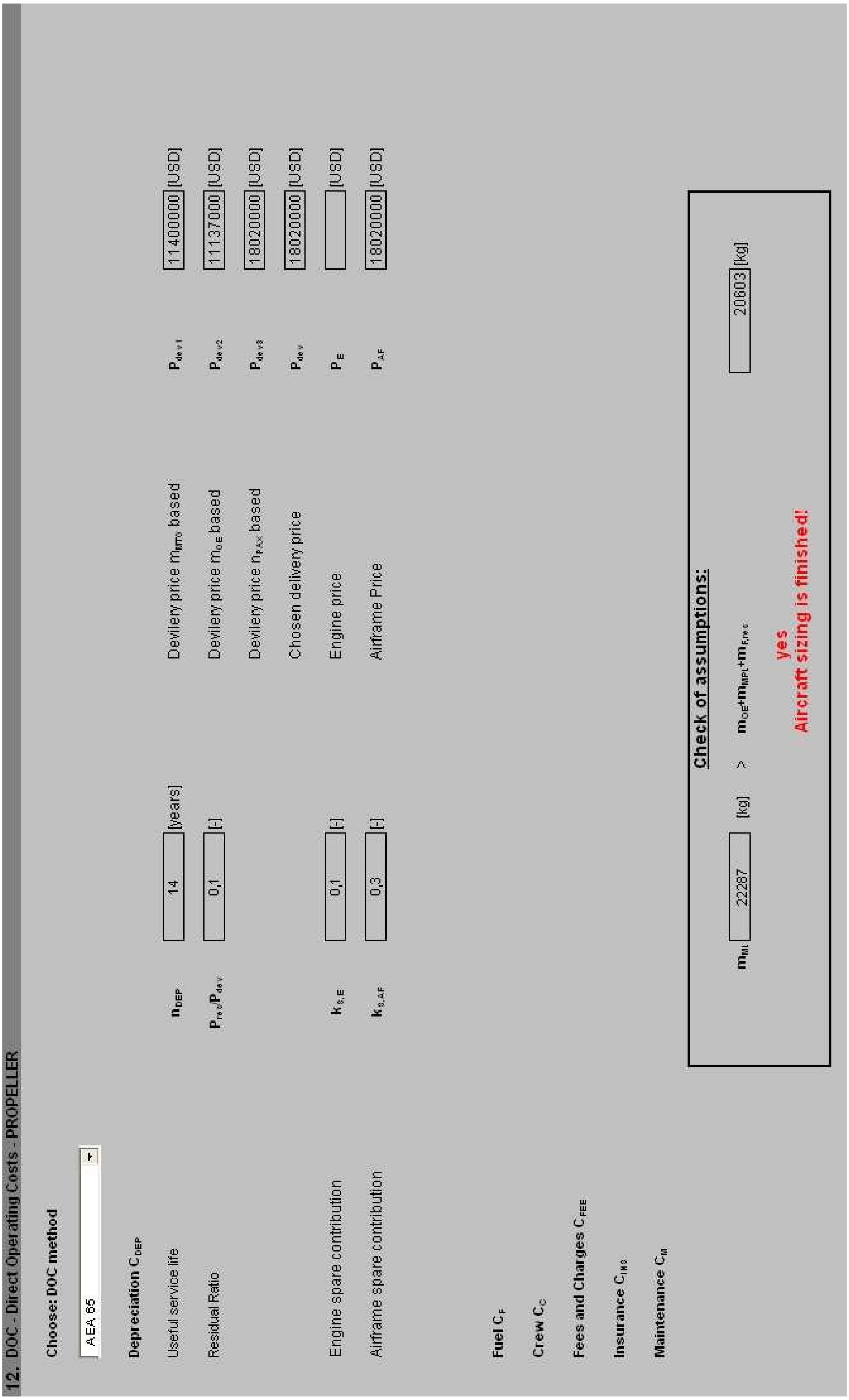

Figure C.11 "DOC - Direct Operating Costs" sub-module