# A Java Toolchain of Programs for Aircraft Design

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**ABSTRACT**

The purpose of this work is to provide a comprehensive overview of JPAD (Java toolchain of Programs for Aircraft Design), a java-based framework conceived as a fast and efficient tool useful as support in the preliminary design phases of an aircraft, and during its optimization process. The software platform is made to perform fast multi-disciplinary analysis of an established aircraft configuration and to search for an optimized configuration in a domain, whose boundaries are defined by the user. The following sections will focus on the description of the software structure and on the results obtained from a case study carried out assuming as baseline a regional turboprop aircraft model similar to ATR-72.

**KEYWORDS**: **AIRCRAFT DESIGN, SOFTWARE ENGINEERING, JAVA**

## NOMENCLATURE

**Latin**
ADP – Aircraft delivery Price
AEA – Association of European Airlines
AEO – All Engines Operative
ATA – Air Transportation Association of America
BFL – Balanced Field Length
$C_a$ – Cost of complete airplane less engine
$C_e$ – Cost of the engine
$C_{noise}$ – Unit noise rate
DAF – Design of Aircraft and Flight technologies research group
DP – Depreciation period
ECAC – European Civil Aviation Conference
$C_L$ – Lifting coefficient
DOC – Direct Operating Costs
FAR - Federal Aviation Regulations
GUI – Graphical user interface
ICAO – International Civil Aviation Organization
JPAD – Java toolchain of Programs for Aircraft Design
$K_{ldg}$ – Landing charges constant
$K_{nav}$ – Navigation charges constant
$K_{grd}$ – Ground charges constant
$L_{approach}$ – Certified noise level, approach measure point
$L_{flyover}$ – Certified noise level, flyover measure point
$L_{lateral}$ – Certified noise level, lateral measure point
LR – Labour rate
$m_{block\ fuel}$ – fuel mass
$M$ – Mach number

MTOW – Maximum Take-Off Weight
$n_e$ – number of engines
$n_{cm}$ – number of crew members
OEI – One Engine Inoperative
OEW – Operating Empty Weight
$P_{fuel}$ – Fuel price
R - Range
$R_a$ – Interest annual rate
$R_i$ – Insurance annual rate
*Re* – Reynolds number
RV – Residual value
T/W – Thrust ratio
$t_b$ – Block time
$t_f$ – Flight time
$T_d$ – Departure airport threshold noise
$T_a$ – arrival airport threshold noise
TI – Total investment
TNAC – Transport Aircraft Noise Classification Group
V – Aircraft speed
$V_b$ – Block speed
W/S – Wing loading
$W_a$ – Empty Weight of the Airplane less Engines
XML – eXtensible Markup Language
XLS – Excel file format

**Greek**

$\alpha_b$ – angle of attack in body reference frame
$\alpha_w$ – angle of attack of the wing in local reference frame

**Subscripts**

$C_{L\,max}$ – Maximum lifting coefficient
$C_{M\,cg}$ – Pitching moment coefficient referred to the aircraft center of gravity
$V_{sTO}$ – Aircraft stall speed in take-off configuration
$Z_{cg}$ – vertical position of the center of gravity in body reference frame

# 1 INTRODUCTION

Nowadays the preliminary design phase of an aircraft is becoming very challenging due to the need for more demanding requirements which deals with different fields of applications. In this perspective, there is a certain need for simple design tools both in aircraft industries and academic research groups which can perform fast and reliable multi-disciplinary analyses and optimizations.

This paper provides a comprehensive overview of JPAD (Java toolchain of Programs for Aircraft Design), a Java-based open-source library conceived as a fast and efficient tool useful as support in the preliminary design phases of an aircraft, and during its optimization process. The library has been completely realized at the Department of Industrial Engineering of the University of Naples "Federico II" where is still in development.

The main goal of this library is to perform fast multi-disciplinary analyses of a parametrically defined aircraft model and to search for an optimized configuration. All the basic principles and approaches to aircraft preliminary design and analysis, followed during the development of the tool, are well described in some Aircraft Design textbooks. [1] [2] [3] [4] [5] [6] [7].

One of the main features of JPAD lies in the smart management of both the aircraft parametric model, which is conceived as a set of interconnected and parameterized components, and the available analyses. The library has been developed with the purpose of simplify the composition of the input file for the user and doing fast analysis with a satisfying grade of accuracy [8] [9]. Section 2 will show the library architecture ant its main advantages. Another key point is the possibility to easily interface JPAD with other external tools in order to achieve a higher level of accuracy.

As stated in [10], the JPAD library is an alternative to a plethora of similar software tools, both freeware and commercial. Most of these tools have an important history, and many of them have been in use for decades. Some of them were conceived with poor software design criteria, have a rigid textual input and come with no visualization features.

This is the main reason why JPAD has been developed paying a lot of attention to simplicity and flexibility. Moreover, it has been conceived as an open-source tool differently from the most popular aircraft design programs available, such as Advance Aircraft Analysis [11], RDS [12] or Piano [13].

JPAD is a general computational library that includes several modules, among which is important to highlight the aerodynamic and stability ones. These are based on several prediction methodologies, developed by the DAF research group of the University of Naples "Federico II", like the ones used for the fuselage [14] [15] or the vertical tail [16] [17] analyses. The capability to develop such methodologies derives from the experience gained by the group, both through numerical analyses and wind tunnel tests, during several years of activity in the field of application of regional turboprop and general aviation aircraft, as explained in [18] [19] [20].

Since JPAD must perform also multi-disciplinary optimizations, the DAF group has growth also in this field of application as described in [21] [22] [23] [24].

## 2 SOFTWARE STRUCTURE

To achieve a clear input file organization a considerable study has been done. The result is an input structure composed by different XML files with the purpose to allow users to easily manage all data needed to execute the desired analyses. In Fig. 1 the entire structure of the software is schematized. It is possible to clearly note that there are two main blocks: input and core.

The input block is defined by two main parts: aircraft and analyses definitions. The first one defines the aircraft model in parametric way using a main file (Aircraft.xml, see Fig. 3) which collects all the components, linking them to their related xml file (i.e. fuselage.xml, vtail.xml, and so on) which contains all geometrical data.

The second one defines all necessary data for each analysis presents into core module (see Fig. 2). Since the aircraft model contains only geometrical data, it is necessary to define several further data referred to each analysis.

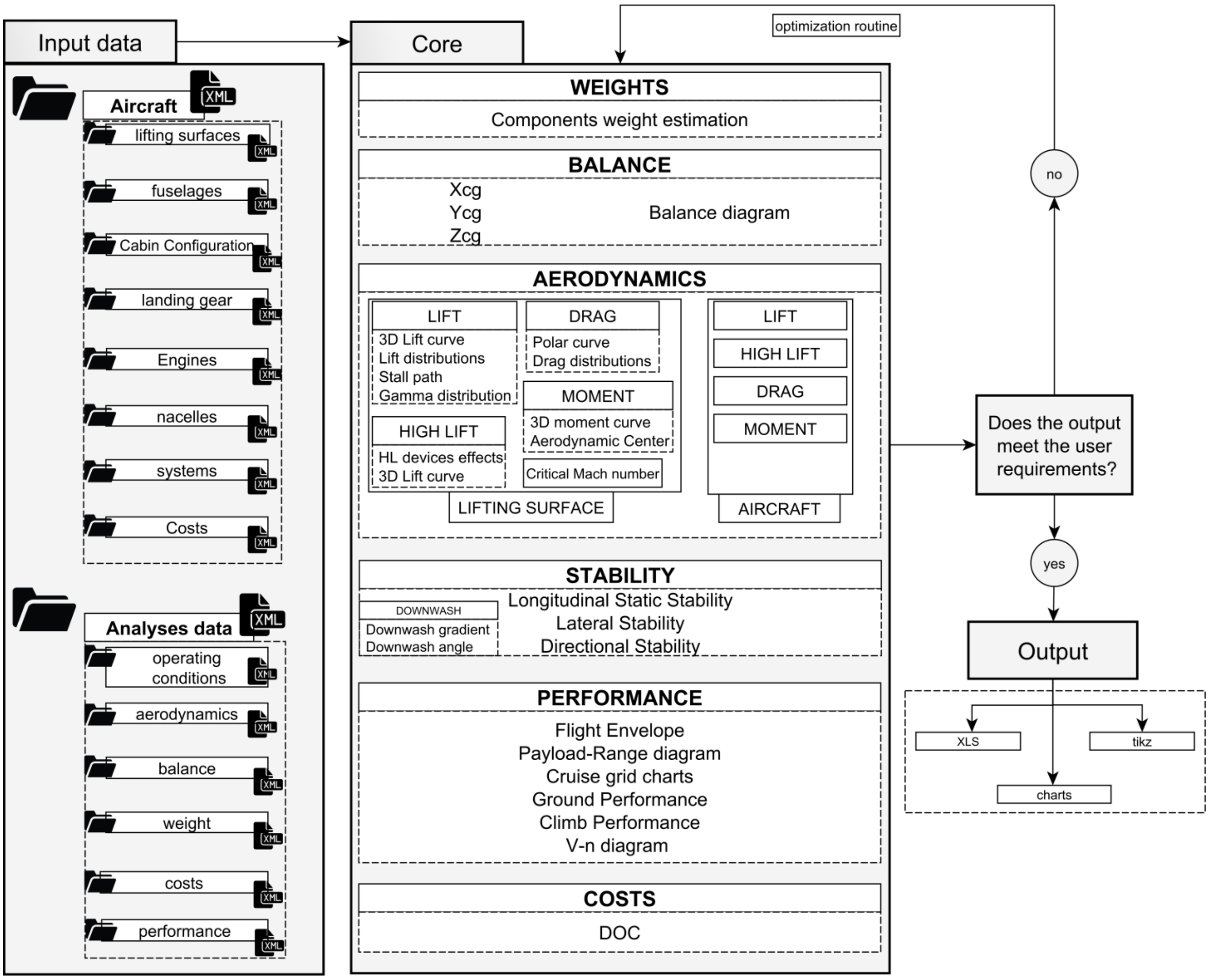


**Figure 1: JPAD schematic flow-chart.**

```xml
<?xml version="1.0" encoding="utf-8"?>
<jpad_config>
                <!-- Input data, shared across analysis tasks -->
                <global_data>
                        <n_limit>2.5</n_limit>
                        <cruise_lift_coefficient>0.45</cruise_lift_coefficient>
                        <reference_range unit="nmi">825</reference_range>
                        <maximum_altitude_at_maximum_speed unit="ft">16000</
                            maximum_altitude_at_maximum_speed>
                        <maximum_cruise_mach_number>0.43</
                            maximum_cruise_mach_number>
                        <optimum_cruise_altitude unit="ft">16000</
                            optimum_cruise_altitude>
                        <optimum_cruise_mach_number>0.45</
                            optimum_cruise_mach_number>
                        <block_time unit="h">1.5</block_time>
                        <flight_time unit="h">1.35</flight_time>
                </global_data>
                <!-- Required analysis tasks -->
                <analyses id="JPAD Test analysis">
                        <weights
                                file="analysis_weights.xml"
                                method_fuselage="JENKINSON"
                                method_wing="ROSKAM"
                                method_htail="JENKINSON"
                                method_vtail="JENKINSON"
                                method_canard=""
                                method_nacelles="TORENBEEK_1976"
                                method_landing_gears="ROSKAM"
                                method_systems="TORENBEEK_2013"
                                /> <!-- method_XXX="AVERAGED" if not present -->
                        <balance
                                file="analysis_balance.xml"
                                method_fuselage=""
                                method_wing=""
                                method_htail=""
                                method_vtail=""
                                method_canard=""
                                /> <!-- method_XXX="AVERAGED" if not present -->
                        <aerodynamics file="analysis_aerodynamics.xml"/>
                        <performance file="analysis_performance.xml"/>
                        <costs file="analysis_costs.xml"/>
                </analyses>
</jpad_config>
```

**Figure 2: An example of the analysis.xml file.**

Aircraft.xml

```xml
<?xml version="1.0" encoding="utf-8"?>
<jpad_config>
        <aircraft id="JPAD Test Aircraft DAF-2016" type="JET" regulations="FAR_25">
                <global_data>
                        <cabin_configuration file="cabin_configuration.xml">
                        </cabin_configuration>
                </global_data>
                <lifting_surfaces>
                        <wing file="wing.xml">
                                <position>
                                        <x unit="m">12.0</x>
                                        <y unit="m">0.0</y>
                                        <z unit="m">-0.5</z>
                                </position>
                                <rigging_angle unit="deg">2.0</rigging_angle>
                        </wing>
                        <horizontal_tail file="htail.xml">
                        <vertical_tail file="vtail.xml">
                </lifting_surfaces>
                <fuselages>
                        <fuselage file="fuselage.xml">
                </fuselages>
                <power_plant>
                        <engine file="engineTurbofan.xml">
                        <engine file="engineTurbofan.xml">
                </power_plant>
                <nacelles>
                        <nacelle file="nacelle.xml">
                        <nacelle file="nacelle.xml">
                </nacelles>
                <landing_gears file="landing_gear.xml">
                </landing_gears>
                <systems file="systems.xml">
                </systems>
</aircraft>
</jpad_config>
```

Wing.xml

```xml
<?xml version="1.0" encoding="utf-8"?>
<jpad_config>
        <aircraft id="JPAD Test Aircraft DAF-2016" type="JET" regulations="FAR_25">
                <global_data>
                        <main_spar_non_dimensional_position type="PERCENT_CHORD"
                            ref_to="LOCAL_CHORD">0.25</
                            main_spar_non_dimensional_position>
                        <secondary_spar_non_dimensional_position type="
                            PERCENT_CHORD" ref_to="LOCAL_CHORD">0.55</
                            secondary_spar_non_dimensional_position>
                        <composite_correction_factor>0.1</
                            composite_correction_factor>
                        <roughness unit="m">0.405e-5</roughness>
                </global_data>
                <equivalent_wing>
                        <surface unit="m^{2}">36.9</surface>
                        <aspect_ratio>13.09</aspect_ratio>
                        <non_dimensional_span_station_kink>0.363</
                            non_dimensional_span_station_kink>
                        <sweep_quarter_chord unit="deg">12.56</sweep_quarter_chord>
                        <twist_at_tip unit="deg">-2.5</twist_at_tip>
                        <dihedral unit="deg">2.5</dihedral>
                        <taper_ratio>0.556</taper_ratio>
                        <x_offset_root_chord_leading_edge unit="m">0.477</
                            x_offset_root_chord_leading_edge>
                        <x_offset_root_chord_trailing_edge unit="m">0.367</
                            x_offset_root_chord_trailing_edge>
                        <airfoils>
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                                <airfoil_kink file="naca63209.xml"/>
                                <airfoil_tip file="naca63209.xml"/>
                        </airfoils>
                </equivalent_wing>
                <panels>
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                        </panel>
                        <panel id="Outer panel" linked_to="Inner panel">
                        </panel>
                </panels>
                <symmetric_flaps>
                </symmetric_flaps>
                <slats>
                </slats>
                <asymmetric_flaps>
                </asymmetric_flaps>
                <spoilers>
                </spoilers>
</aircraft>
</jpad_config>
```

**Figure 3: An extract from a general aircraft.xml input file.**

The structure described above allows to generate different aircrafts, or different configurations of the same model, combining different components. Table 1 shows how to generate several aircrafts starting from a given reference model, by changing the wing and the power plant.

**Table 1: Creation of different aircraft models from the same reference**

| **REFERENCE** | **NEW MODEL 1** | **NEW MODEL 2** | **NEW MODEL 3** |
|---|---|---|---|
| FUSELAGE | FUSELAGE | FUSELAGE | FUSELAGE |
| WING | **WING 1** | **WING 2** | **WING 3** |
| HORIZONTAL TAIL | HORIZONTAL TAIL | HORIZONTAL TAIL | HORIZONTAL TAIL |
| VERTICAL TAIL | VERTICAL TAIL | VERTICAL TAIL | VERTICAL TAIL |
| POWER PLANT | **POWER PLANT 1** | **POWER PLANT 2** | **POWER PLANT 3** |
| LANDING GEAR | LANDING GEAR | LANDING GEAR | LANDING GEAR |

The possibility to generate a series of different aircrafts in a simple and fast way, allows to easily perform comparisons between these latter. For example, assuming different wings and engines as shown in Table 1, it is possible to estimate the effects that some design parameters have on a specific output. Fig. 4 shows how the FAR-25 take-off field length behaves with different values of the wing surface and the engine static thrust at fixed aircraft maximum take-off weight. This feature plays also a key role in the optimization process described in Fig. 1.

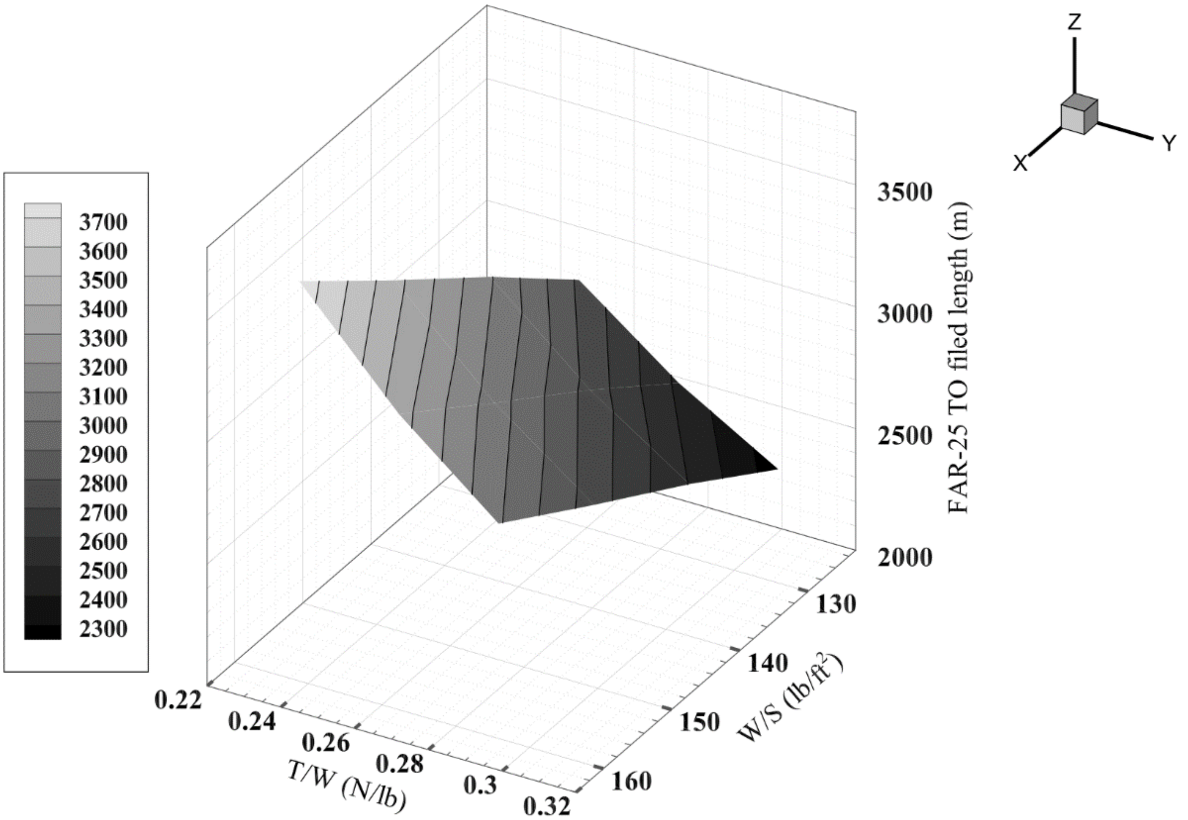


**Figure 4: FAR-25 take-off field length at different wing loadings W/S and thrust-weight ratios T/W.**

In the same way, it is possible to perform a complete analysis (those present into core block in Fig. 1), or a specific one, combining different analyses files (see Fig. 2). This allows an easier evaluation of generic cost function during optimization tasks resulting in reduced amount of computational costs required for this kind of operations.
Besides the input, the second main block is the core which manages all the available analyses. This contains several independent modules, as shown in the Fig. 1, that deals with following application fields.

- **Weights**: estimates the aircraft weight breakdown starting from a first guess maximum take-off weight and some mission requirements. In particular, it evaluates each aircraft component mass using well-known semi-empirical equations *[1] [5] [6] [7]*
- **Balance**: estimates the center of gravity position related to each weight condition and draws the balance diagram.
- **Aerodynamics and Stability**: the aerodynamics module estimates all the aerodynamic characteristics concerning lift, drag and moments coefficients at different operating conditions for each aircraft component (wing, tails, fuselage and nacelles). Whereas the stability module gives useful data about static stability of the whole aircraft considering non-linearity effects as well.
- **Performance**: evaluates most important aircraft performance such as Payload-Range diagram, mission profile, cruise flight envelope, ground performance, climb performance and the cruise grid chart.
- **Costs**: estimates the DOC breakdown.

JPAD allows to obtain different kind of output: charts and data in XLS format (as shown in Fig. 5). In this way, the comparison between two or more aircraft (or simply between slightly different configurations of the same aircraft) is easier and more efficient.

| Description | Unit | Value |
|---|---|---|
| Ground roll distance | m | 763.4976659 |
| Rotation distance | m | 165.4983558 |
| Airborne distance | m | 231.5465274 |
| AEO take-off distance | m | 1160.542549 |
| FAR-25 take-off field length | m | 1334.623931 |
| Balanced field length | m | 1225.663607 |
| | | |
| Ground roll distance | ft | 2504.913602 |
| Rotation distance | ft | 542.9736083 |
| Airborne distance | ft | 759.6670847 |
| AEO take-off distance | ft | 3807.554295 |
| FAR-25 take-off field length | ft | 4378.687439 |
| Balanced field length | ft | 4021.20606 |
| | | |
| Stall speed take-off (VsTO) | m/s | 53.67149021 |
| Decision speed (V1) | m/s | 55.82318509 |
| Rotation speed (V_Rot) | m/s | 56.35506473 |
| Minimum control speed (VMC) | m/s | 46.98027511 |
| Lift-off speed (V_LO) | m/s | 60.77409554 |
| Take-off safety speed (V2) | m/s | 63.95159767 |
| | | |
| Stall speed take-off (VsTO) | kn | 104.3290307 |
| Decision speed (V1) | kn | 108.5115909 |
| Rotation speed (V_Rot) | kn | 109.5454822 |
| Minimum control speed (VMC) | kn | 91.32234902 |
| Lift-off speed (V_LO) | kn | 118.1353909 |
| Take-off safety speed (V2) | kn | 124.3119609 |
| | | |
| V1/VsTO | | 1.04 |
| V_Rot/VsTO | | 1.05 |
| VMC/VsTO | | 0.88 |
| V_LO/VsTO | | 1.13 |
| V2/VsTO | | 1.20 |
| | | |
| Take-off duration | s | 31.51824683 |

TAKE-OFF | CLIMB | CRUISE | DESCENT | LANDING | MISSION PROFILE | PAYLOAD-RANGE

**Figure 5: A detail of the output XLS file for the performance analysis.**

An important element of JPAD is the graphical user interface (GUI). The GUI of JPAD is completely designed using the JavaFX library *[25]* and the related development tool JavaFX Scene Builder *[26]*. Building the GUI means to find a perfect compromise between functionalities and simplicity. In fact, JPAD must handle the management of an entire aircraft as well as complex multi-disciplinary analyses and optimizations. To make as easier as possible the use of this tool, a sort of wizard paradigm has been used to guide the user from the definition of the aircraft model to the output visualization, passing through the analyses manager.
At first, as shown in Fig. 6, the user must define all the folders in which the software expects to find the following resources:

- the input files;
- the external resources, such as engine decks and databases containing data about methodologies formulation;
- the folder in which all the output files and charts must be stored.

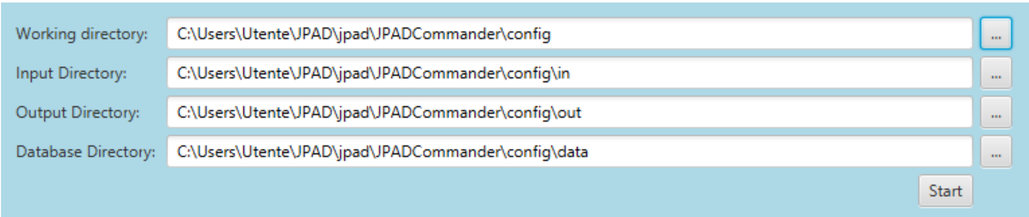


**Figure 6: Definition of the required folders.**

After that the user must follow the guideline of the main three buttons shown in Fig. 7. Focusing on the input manager, the user can simply define an aircraft model by loading it from an external XML file, or by choosing it among a list of possible default aircrafts.
The structure of this manager has been designed using different tabs; this with the aim of giving a complete overview of the aircraft, and its component, without having to manage too many data all in one time.
As shown in Fig. 8, each tab is provided with an input area with all the text fields related to every single data, a text area with a detailed overview of the object in exam, and the graphic representation of the component with its three views.

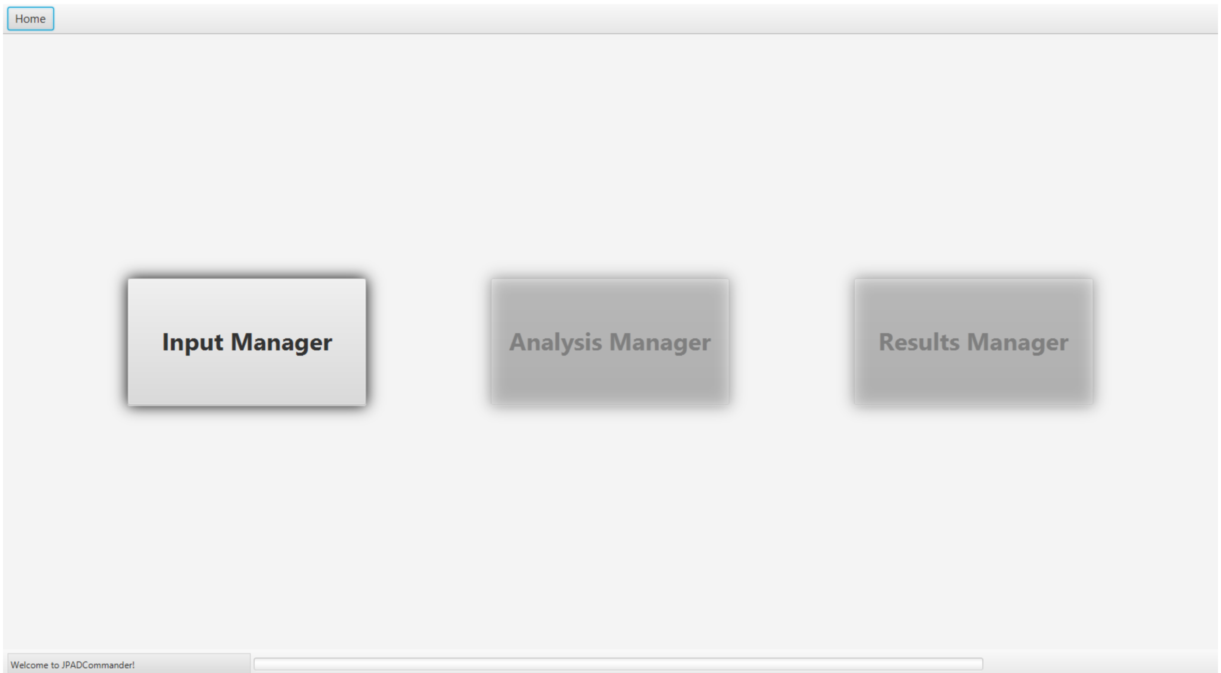


**Figure 7: JPAD GUI main view.**

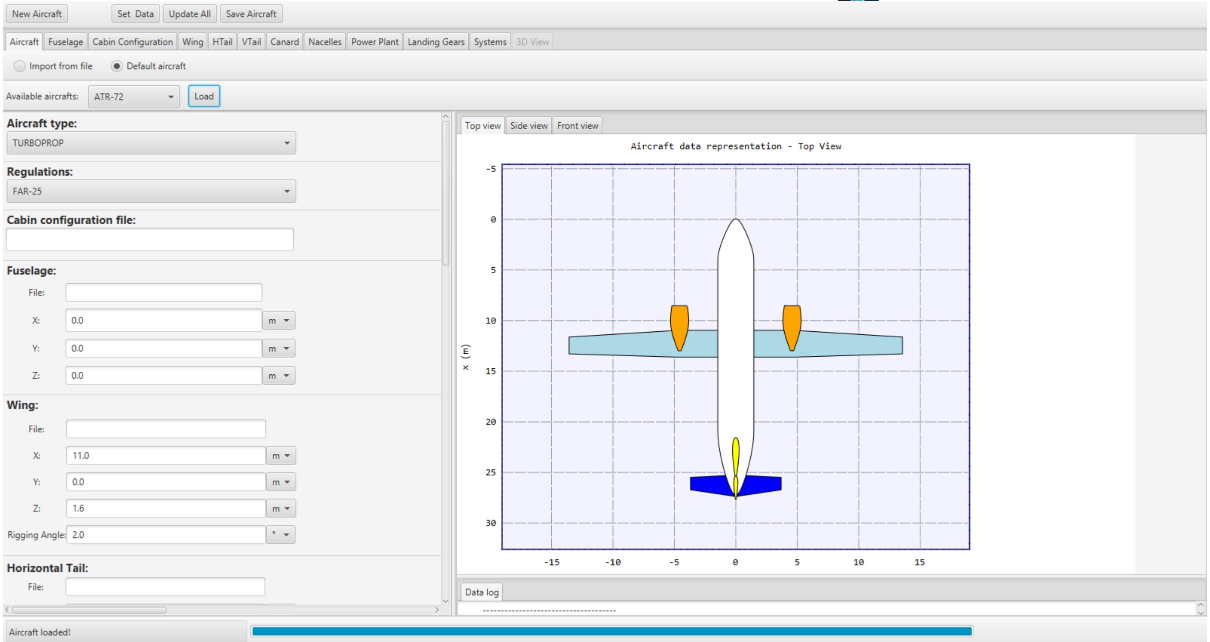


**Figure 8: JPAD GUI input manager view.**

## 3 CASE STUDY: ATR-72

To show the potentiality of the JPAD library, a multi-disciplinary analysis has been performed assuming a parametric aircraft model similar to the ATR-72. The analysis results that will be reported concerns lift and longitudinal static stability analysis (including the non-linear effects) as well as some of the main performance and the DOC. These latter will also be compared to public domain data from online brochures and flight manuals.

### 3.1 Aerodynamics and Longitudinal Stability

Using JPAD, is possible to evaluate the lift coefficient curve both of an airfoil, by means of the internal aerodynamic database based on [27], and of a 3D lifting surface as shown in the Fig. 9 using data in Table 2.

**Table 2: ATR-72 model airfoil data**

| Station | Airfoil | *Re* | $C_{L\,max}$ |
|---|---|---|---|
| Root | NACA 23018 | $6.28 \cdot 10^6$ | 1.65 |
| Kink | NACA 23018 | $6.28 \cdot 10^6$ | 1.65 |
| Tip | NACA 23015 | $4.41 \cdot 10^6$ | 1.70 |

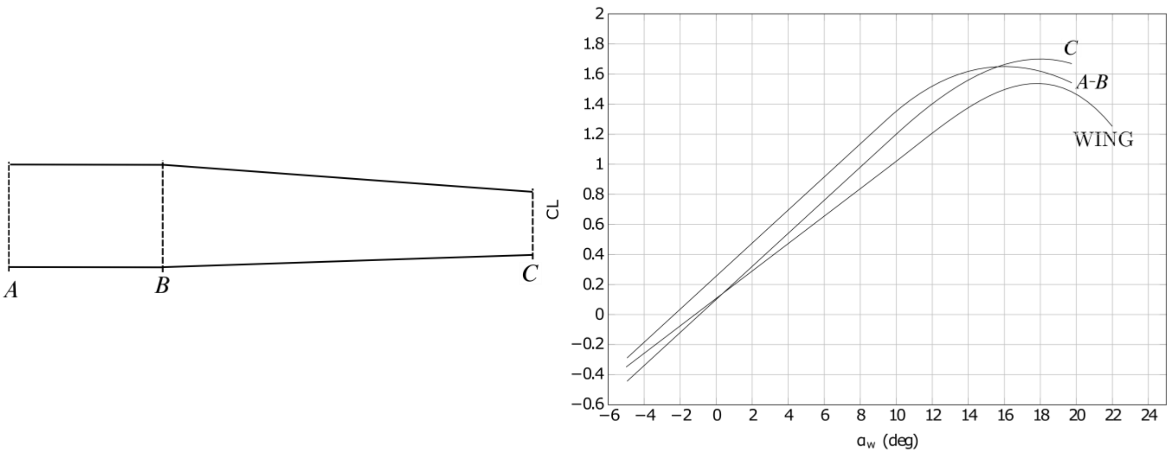


**Figure 9: 2D and 3D lift results for regional turboprop. M=0.2.** *[28]*

All aerodynamic results are then incorporated in the module in charge of the longitudinal static stability analysis, which can be executed for a given aircraft at a fixed flight condition.
An important JPAD innovation is that the downwash gradient and the related angle have been evaluated considering a variable distance between the horizontal tail and the wing, improving the formulations proposed in [29]. In this way, the downwash calculation turns out to be more accurate.
The distances in the downwash angle formula are not considered between the aerodynamic center of wing and the aerodynamic center of horizontal tail as usual, but variable and they are measured from the vortex shed plane behind the wing to the horizonal tail. In order to perform this improved method an iterative process is necessary.
First, referring to Fig. 10, it is necessary to evaluate the geometrical distances $m_0$ and $x_0$ described below.

- $x_0$: distance between the aerodynamic centre of the wing and the aerodynamic centre of the horizontal tail calculated along the x axis.
- $m_0$: distance between the aerodynamic centre of the horizontal tail and the horizontal line passing through the trailing edge of the airfoil root of the wing.

Then, starting from a value of a $\alpha_a = 0°$ (and $\varepsilon = 0°$) and proceeding with an increase of angle of attack equal to $\Delta\alpha$, it is possible to evaluate the distances m and r geometrically for each angle of attack using Eq.1 and Eq. 2. These two distances allow to calculate the downwash angle using the formula proposed in [29], but they depend, in turn, on the downwash angle, so an iterative process is necessary.

$$m\big|_i = d\sin\left(\psi + i_w - \alpha_{0_L} - i\Delta\alpha + \varepsilon\right) \tag{1}$$

$$x\big|_i = d\cos\left(\psi + i_w - \alpha_{0_L} - i\Delta\alpha + \varepsilon\right) + \frac{3}{4}c_r\cos\left(-\alpha_{0_L} - i\Delta\alpha + \varepsilon\right) \tag{2}$$

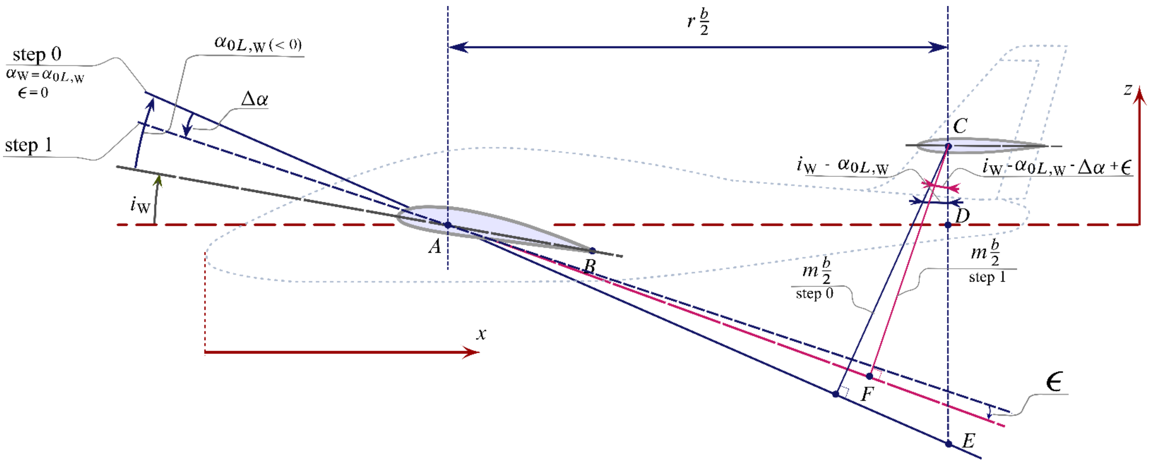


**Figure 10: Arm definitions for downwash evaluation.**

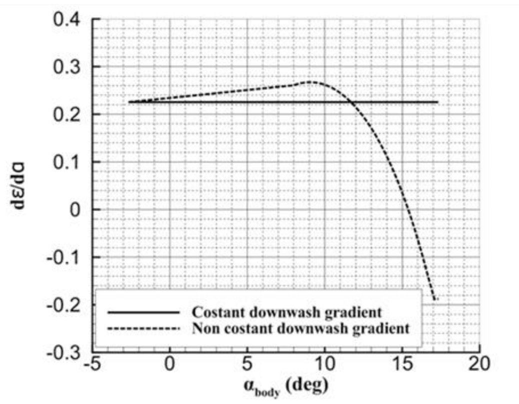


**Figure 11: Variability of downwash gradient at M=0.4.** [28]

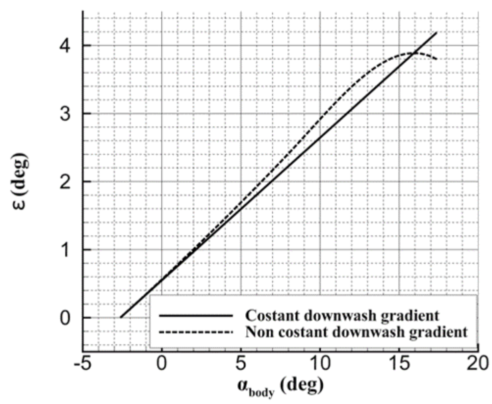


**Figure 12: Variability of downwash angle at M=0.4.** [28]

The stability calculation considers also the propulsion effects, the fuselage pitching moment effect [14], and the pendular stability due to the axial component of the aerodynamic force.
The charts from Fig. 11 to Fig. 15 show the results obtained for the regional turboprop under examination.

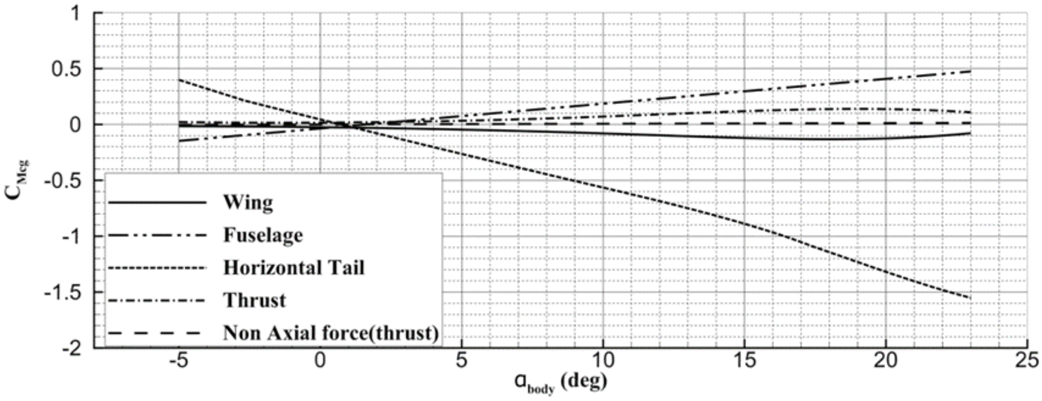


**Figure 13: $C_{Mcg}$ vs. $\alpha_b$ of aircraft components – Cruise condition.** [28]

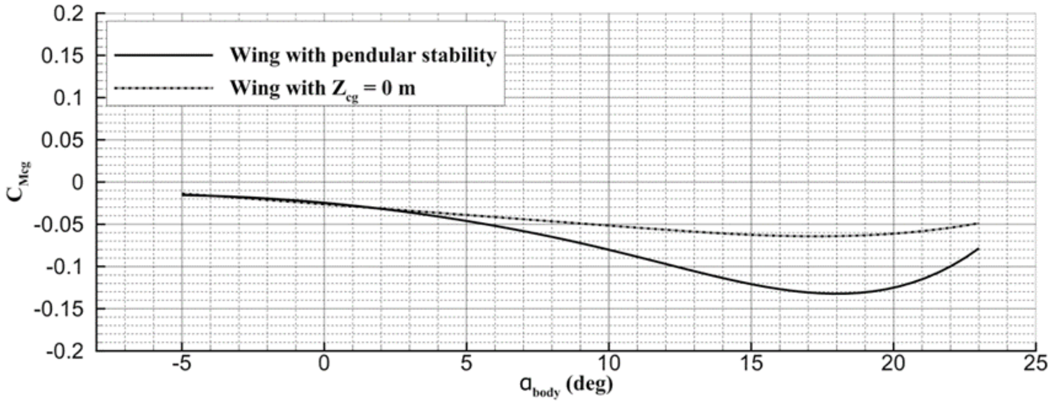


**Figure 14: $C_{Mcg}$ vs. $\alpha_b$ for the wing with and without pendular stability – Cruise condition.** [28]

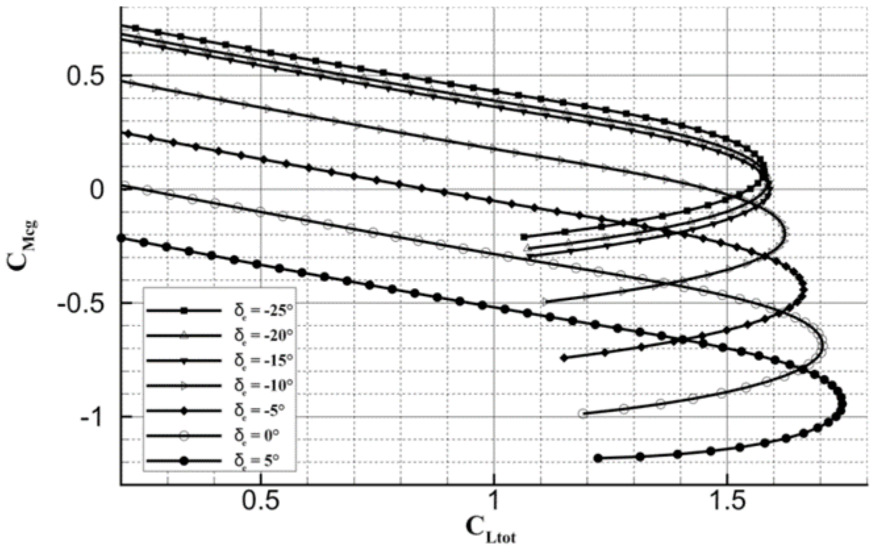


**Figure 15: $C_{M\,cg}$ vs. $C_{L\,tot}$ with elevator deflections – Cruise condition.** *[28]*

### 3.2 Performance

Most of the performance analyses carried out by JPAD are simulation-based to achieve a higher fidelity level with respect to classical semi-empirical formulations. One remarkable example can be found in [10] concerning the ground performance evaluation.
JPAD can perform in less than 30 seconds the following performance calculations using the results of the aerodynamics and stability module.

- Take-off
- Climb (AEO and OEI)
- Cruise
- Descent
- Landing
- Mission profile analysis
- Payload-Range
- Flight maneuvering and gust envelope

To show the level of accuracy achieved by JPAD, some relevant performance will be compared with the data from the brochure of the ATR-72 [30]. Fig. 16 to Fig. 18 show respectively the Payload-Range chart, the balanced field length evaluation and the cruise flight envelope; while Table 3 provides the above-mentioned numerical comparisons. To perform these analyses a turboprop engine deck has been modeled starting from the ones proposed in literature.

**Table 3: Numerical comparisons between JPAD performance and public domain data**

| PERFORMANCE | JPAD | ATR-72 brochure [30] | Difference (%) |
|---|---|---|---|
| Design Range (with 68 passengers at 95kg) | 890 Nm | 890 Nm | <1.0% |
| Balanced Field Length | 1225 m | 1223 m | <1.0% |
| FAR-25 Landing Field Length | 1162 m | 1048 m | 10.9% |
| Max cruise Mach number at 17kft | 0.440 | 0.444 | <1.0% |
| Service ceiling AEO | 26709 ft | 25000 ft | 6.8% |
| Service ceiling OEI | 14712 ft | 14200 ft | 3.6% |

As can be seen from Table 3, the maximum difference between the JPAD output and the brochure data is never bigger than 11% proving the reliability of the library. The biggest difference can be found in the FAR-25 landing field length and this may be due to the use of a simplified semi-empirical evaluation of the airborne phase, or to the uncertainty of some simulation parameters of the ground roll phase.

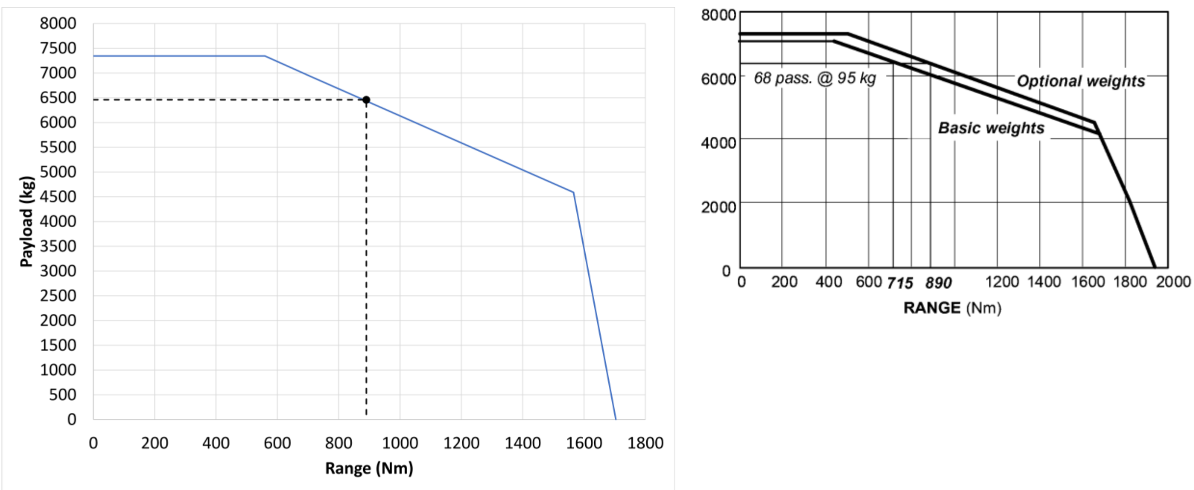


**Figure 16: Payload-Range comparison between JPAD (left) and the ATR-72 brochure** [30] **(right) for the optional weights condition.**

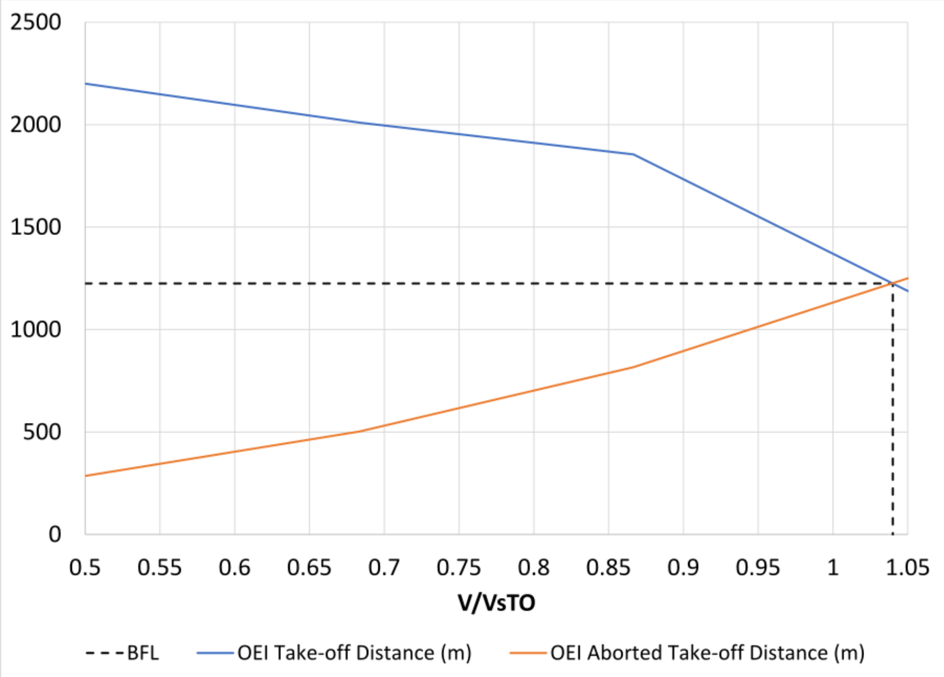


**Figure 17: Balanced Field Length evaluation in JPAD**

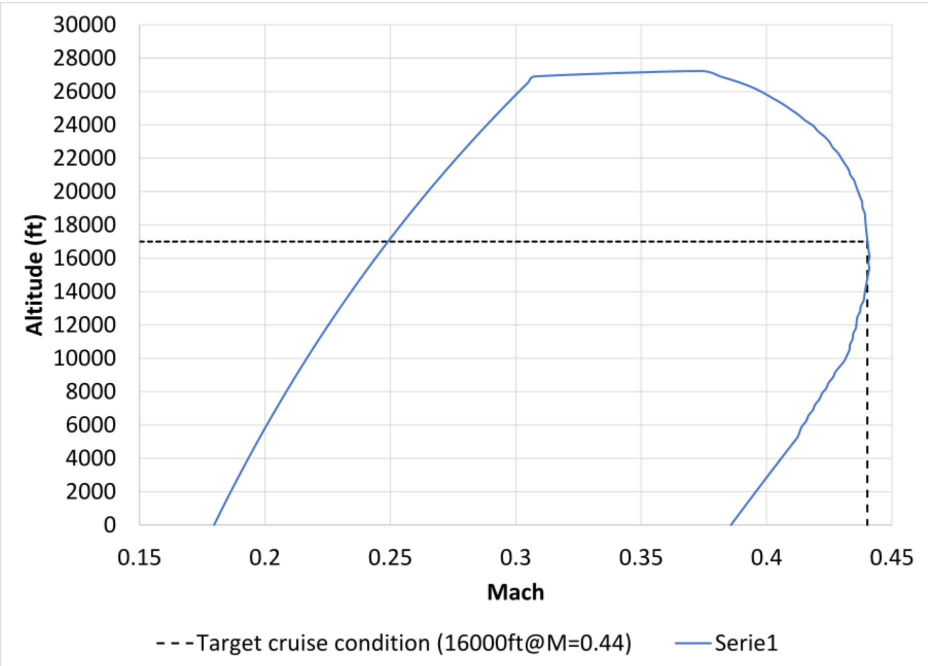


**Figure 18: Cruise flight envelope evaluation in JPAD**

### 3.3 Costs

An import feature of JPAD is the capability of the estimation of the Direct Operating Costs (DOC). This concerns flight operations and consider different items:

- **Capital costs**: depreciation, interest, and insurance.
- **Fuel cost**.
- **Charges**: landing, navigation, ground handling, noise, emissions.
- **Crew costs**: flight and cabin.
- **Direct maintenance**: airframe and engine

To estimate these cost items, the methodologies defined by AEA [31] for capital, fuel, a part of charges (landing, navigation and ground-handling) and crew costs has been implemented while the ATA [32] method has been used for direct maintenance costs. Noise charges are calculated by using the formulation recommended by the Transport Aircraft Noise Classification Group (TNAC) within the European Civil Aviation Conference (ECAC) [33] [34]. The emissions charges are estimated using formulation prescribed by ICAO in annex 16 volume 2 [35]. The equations implemented into the costs module of the code are reported in the Table 4 (from Eq. (3) to Eq. (19)).

**Table 4 DOC equations**

| | | | |
|---|---|---|---|
| **Capital costs** | Depreciation | $DOC_{DEP} = \frac{TI}{DP}(1-RV)$ | (3) |
| | Interest | $DOC_{INS} = R_a \cdot ADP$ | (4) |
| | Insurance | $DOC_{INT} = R_i \cdot TI$ | (5) |
| **Fuel cost** | | $DOC_{FUEL} = \mathrm{P}_{fuel} \cdot m_{block\ fuel}$ | (6) |
| **Charges** | Landing | $DOC_{ldg} = K_{ldg} \cdot MTOM$ | (7) |
| | Navigation | $DOC_{nav} = K_{nav} \cdot R \cdot \sqrt{\frac{MTOM}{50}}$ | (8) |
| | Ground-Handling | $DOC_{grd} = K_{grd} \cdot PL$ | (9) |
| | Noise | $DOC_{noise} = C_{noise} \times \left( 10^{\left(L_{approach} - Ta\right)/10} + 10^{\left(\left(L_{flyover} + L_{lateral}\right)/2 - Td\right)/10} \right)$ | (10) |
| | Emissions: NOx | $DOC_{NOx} = C_{NOX} \cdot m_{NOX,\,LTO} \cdot a$ | (11) |
| | | $DOC_{CO} = C_{CO} \cdot m_{CO,\,LTO} \cdot a$ | (12) |
| | | $DOC_{HC} = C_{HC} \cdot m_{HC,\,LTO} \cdot a$ | (13) |
| **Crew costs** | Flight | $DOC_{COCKPIT\ CREW} = LR_{COCKPIT} \cdot n_{cm}$ | (14) |
| | Cabin | $DOC_{CABIN\ CREW} = LR_{CABIN} \cdot n_{cm}$ | (15) |
| **Direct maintenance costs** | Airframe: Material | $DOC_{AF\ MAT} = \frac{\left(C_{FHa} \cdot t_f + C_{FCa}\right)}{V_B \cdot t_B}$ <br> $C_{FHa} = 3.08 \cdot \frac{C_a}{10^6}$ $\quad C_{FCa} = 6.24 \cdot \frac{C_a}{10^6}$ | (16) |
| | Labour | $DOC_{AF\ LAB} = \frac{\left(K_{FHa} \cdot t_f + K_{FCa}\right) \cdot LR \cdot \sqrt{M}}{V_B \cdot t_B}$ <br> $K_{FCa} = 0.05 \cdot \frac{W_a}{1000} + 6 - \frac{630}{\left(W_a/1000 + 120\right)}$ <br> $K_{FHa} = 0.59 \cdot K_{FCa}$ | (17) |
| | Engine: Material | $DOC_{E\ MAT} = \frac{\left(C_{FHe} \cdot t_f + C_{FCe}\right)}{V_B \cdot t_B}$ <br> $C_{FCe} = 2.0 \cdot n_e \cdot \frac{C_e}{10^5}$ $\quad C_{FHe} = 2.5 \cdot n_e \cdot \frac{C_e}{10^5}$ | (18) |

| | | | |
|---|---|---|---|
| | Labour | $DOC_{E\,LAB} = \dfrac{(K_{FHe} \cdot t_f + K_{FCe}) \cdot LR}{V_B \cdot t_B}$ <br> $K_{FCe} = \left(0.3 + 0.03 \cdot \dfrac{T}{1000}\right) \cdot n_e$ <br> $K_{FHe} = \left(0.6 + 0.027 \cdot \dfrac{T}{1000}\right) \cdot n_e$ | (19) |

**Table 5 Economic assumptions for DOC**

| **Economic Assumptions** | | |
|---|---|---|
| Life span | 12 | years |
| Residual value | 0.2 | |
| No. seats | 68 | |
| Aircraft price | 14.4 | Mil.$ |
| Engine price (each) | 1.0 | Mil.$ |
| Spares | 1.84 | Mil.$ |
| Interest | 5.0% | per year |
| Insurance | 1.0% | per year |
| No. of flights | 2700 | flights |
| Utilisation | 2484 | hr/year |
| Block Time | 0.92 | hr |
| Block Fuel (mission) | 611 | kg |
| Fuel Price | 0.8 | $/gal |

**Table 6 Data for DOC estimation**

| **Performance** | | |
|---|---|---|
| Range (Mission) | 200 | nm |
| Mach cruise | 0.44 | |
| Power | 2750 | shp |
| SFC | 0.45 | lbm/lbs*hr |
| TO Thrust | 7700 | lbs |
| No. Engines | 2 | |
| **Weights** | | |
| MTOW | 22000 | Kg |
| OEW | 12950 | Kg |
| PAYLOAD | 7050 | Kg |
| FUEL max | 5000 | Kg |
| Engine Weight | 480 | Kg |
| Airframe Weight | 11990 | Kg |

In this section, to compare the JPAD results with respect to data present in a ATR-72 brochure [30], only the cash DOC composed by fuel, crew, maintenance and charges has been considered. In Table 5 and Table 6 the economic assumptions and weights and performance data used for the comparison are respectively resumed.

The results are shown in Table 7 in terms of cash DOC per trip and pie charts in Fig. 19 and Fig. 20. It is possible to see a good agreement except for the airframe maintenance. This is due to lack of public domain data, both for engine and airframe, which can be useful to conceive a more accurate methodology. The difference in landing charges may be due to the different data environment. In fact, ATR-72 brochure refers to US environment while JPAD uses the formulation suggested by European airliners.

**Table 7 JPAD costs results comparison**

| | BROCHURE ($/trip) [30] | JPAD ($/trip) |
|---|---|---|
| **Fuel** | 182 | 183 |
| **Engine maintenance** | 120 | 148 |
| **Airframe maintenance** | 117 | 261 |
| **Crew** | 145 | 147 |
| **Landing fee** | 109 | 135 |
| **Total cash DOC** | **673** | **868** |

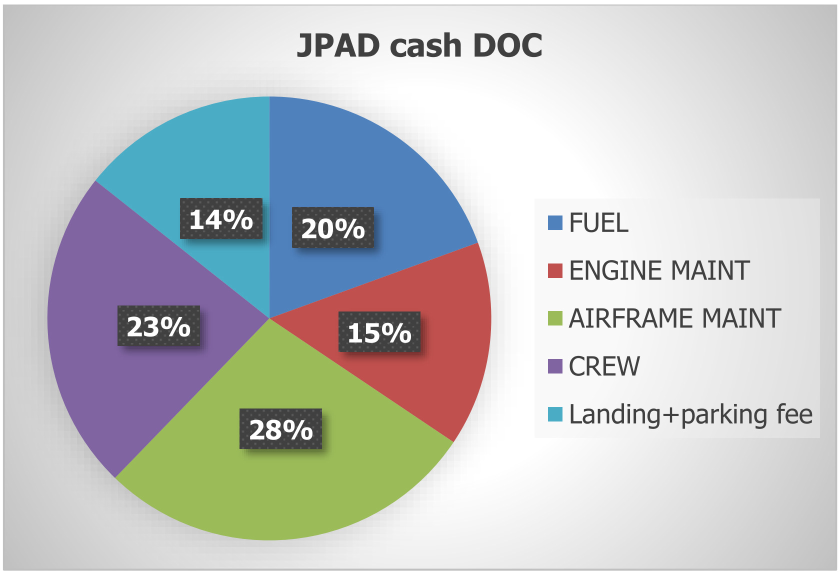


**Figure 19 JPAD estimation of cash DOC for ATR-72**

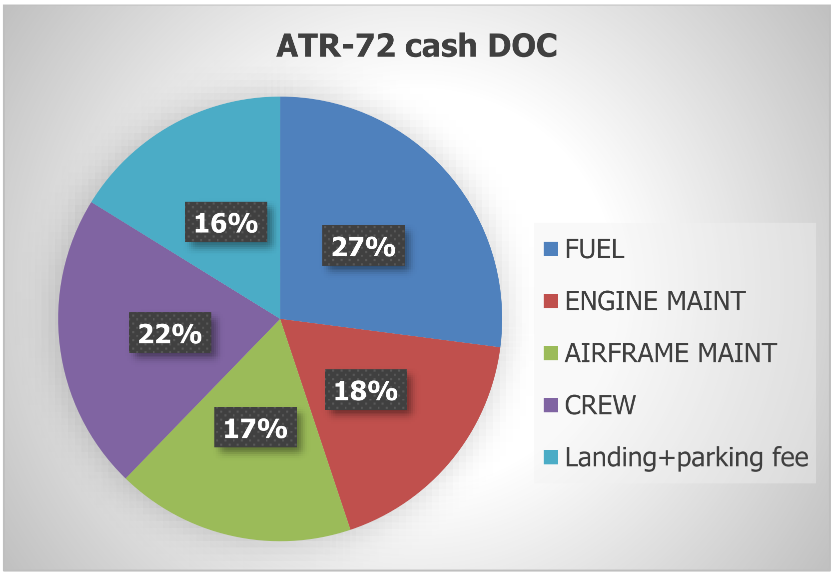


**Figure 20 Cash DOC ATR-72** *[30]*

## CONCLUSION

The purpose of this work was to provide a comprehensive overview of JPAD (Java toolchain of Programs for Aircraft Design). The software structure and the results obtained from a case study has been showed in order to verify the code effectiveness to perform fast multidisciplinary analyses. The first step is to define the geometry by composing different xlm files (fuselage.xml, wing.xml, and so on). In this way is possible to generate different aircrafts in a simple and fast way and it allows to easily perform comparisons between several aircrafts. This feature plays a key role in the optimization process. In similar manner, user defines the analyses which the code have to perform by filling out the appropriate xml file (Analysis_Weights.xml, Analysis_Performance.xml, and so on). Results are clearly collected into excel files. The entire process lasts only a few seconds (less than a minute). The research group is currently working on the communication of JPAD with external tools such as AVL and USAF Digital Datcom.

## ACKNOWLEDGMENT

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