

CEASIOM: An Open Source Multi Module Conceptual Aircraft Design Tool

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***Abstract** - Following concept sketch and first-guess sizing, the conventional conceptual design process calls for group of specialists to ensure that the designed aircraft meets the requirements of that specialty (i.e. aerodynamics, structures, flight dynamics etc.). Being a multidisciplinary iterative process, involvement of different individuals at person, makes it time consuming and requires extensive effort to keep pace with different disciplines. As a consequence, there is a trend towards replacing this method with computational procedures. The expectation from these computational procedures is a conceptual design of an aircraft, which can be confidently passed to the preliminary design phase. In order to address this need, the Computerized Environment for Aircraft Synthesis and Integrated Optimization Methods (CEASIOM) simulation system has been developed. Significant features developed and integrated in CEASIOM are geometry, aerodynamics, flight dynamics and aero elasticity modules. This paper, after introduction briefly describes the CEASIOM and its module for aircraft conceptual design.*

Keywords: CEASIOM, Conceptual Design, Aero-servo elastic, AcBuilder, SUMO, AMB, NeoCASS, SDSA, FCSDT.

1 Introduction

CEASIOM^[1] is meant to support engineers in the conceptual design process of the aircraft, with emphasis on the improved prediction of stability and control properties achieved by higher-fidelity methods than found in contemporary aircraft design tools. Moreover, CEASIOM integrates into one application the main design disciplines, aerodynamics, structures, and flight dynamics, impacting on the aircraft's performance. It is thus a tri-disciplinary analysis brought to bear on the design of the Aero-servo elastic aircraft. CEASIOM does not however carry out the

entire conceptual design process. It requires as input an initial layout as the baseline configuration that it then refines and outputs as the revised layout. In doing this, CEASIOM, through its simulation modules, generates significant knowledge about the design in the performance, loads, and stability and control databases. The information contained in these databases is sufficient input to a six Degree of Freedom engineering flight simulator. CEASIOM runs under either Windows or Linux, and its only require a MATLAB® license.

2 Brief Description of CEASIOM

CEASIOM, the Computerized Environment for Aircraft Synthesis and Integrated Optimization Methods, developed within the European 6th Framework Programmed .SimSAC^[2] (Simulating Aircraft Stability And Control Characteristics for Use in Conceptual Design), is a framework tool for conceptual aircraft design that integrates discipline-specific tools like: CAD & mesh generation, CFD, stability & control analysis etc. all for the purpose of aircraft conceptual design. CEASIOM is a physics based multi-disciplinary program which steps in the conceptual design phase. The design process is classified into three phases, conceptual design phase at the beginning^[3]. In the following Fig. the course of the action at the conceptual design stage can be understood. The green marked items are covered by CEASIOM. Significant features^[4] developed and integrated in CEASIOM as modules are: AcBuilder, SUMO, AMB, SDSA, NeoCass, FCSDT.

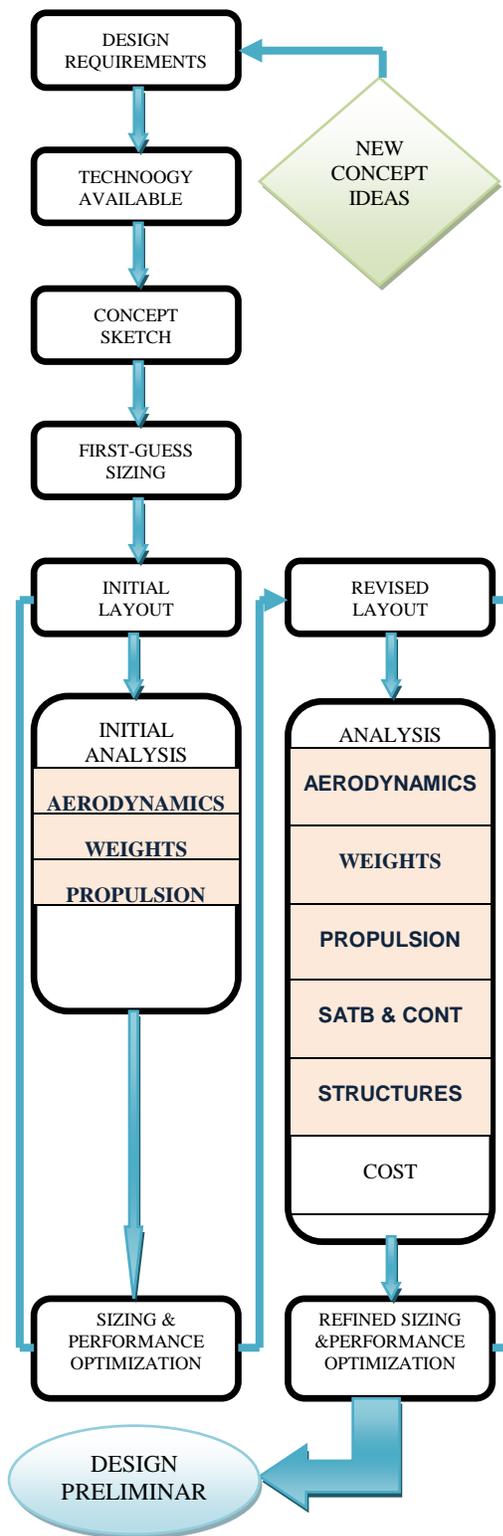


Figure 1. Conceptual Design Phase

The whole CEASIOM format is based on *.xml format. The input *.xml [5] file contains all the parameters which are generally necessary for a geometrical description of an aircraft. The description is based in tree structure like fig.

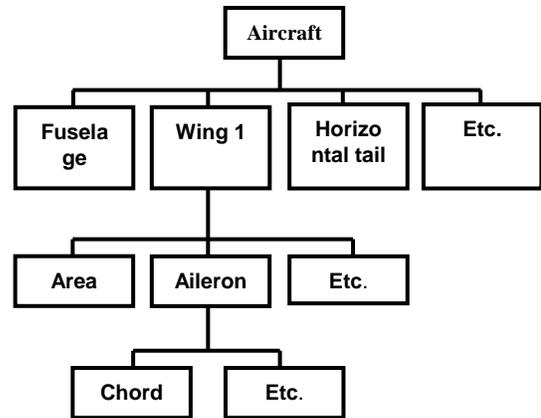


Figure 2. Tree structure of aircraft geometrical data.

The sequence of data flow in CEASIOM is given below:

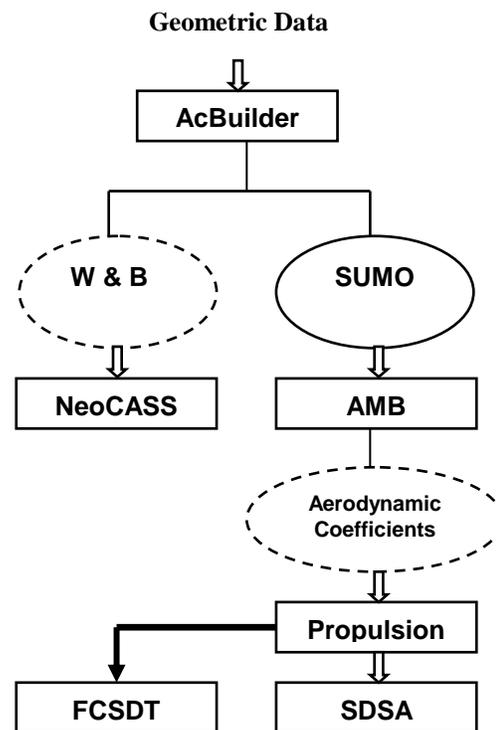


Figure 3. Data Flow in CEASIOM

2.1 Modules of CEASIOM

2.1.1 2.1.1AcBuilder

The starting point of CEASIOM: the aircraft builder [6] module which allow user to define a parameterized geometry of an aircraft and visualize it. Also the input of miscellaneous data can be set. With the help of this module it is possible to import & export the parameters in *.xml format. This way an input file can be generated for AMB module, the NeoCass module and FCSDT. The sub-item of

AcBuilder is: 1.Geometry Definition, 2. Weight & Balance accommodations, 3. Centre of Gravity computation, 4.Technology Definitions. In Geometry module the single characteristics of in view of geometrical components and the fuel are set.

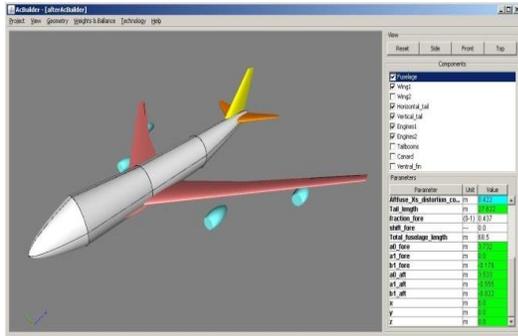


Figure 4. Geometry Definition [4]

The integrated weight & balance module [7] is relevant for the first estimation of overall weight & inertias.

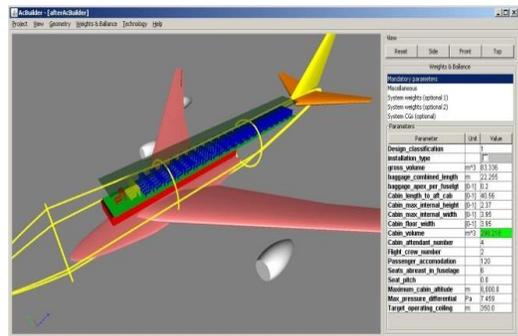


Figure 5. Weight & Balance Accommodations[4]

The position Centre of Gravity is located through CG computation module.

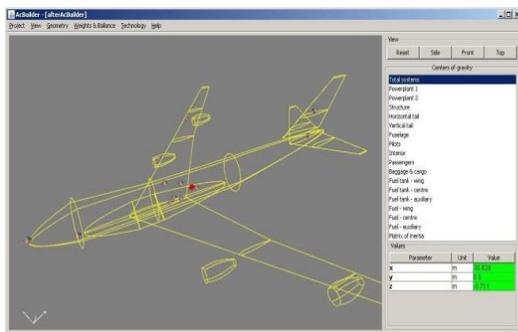


Figure 6. Centre of Gravity computation [4]

The technology module is significant for structural sizing.

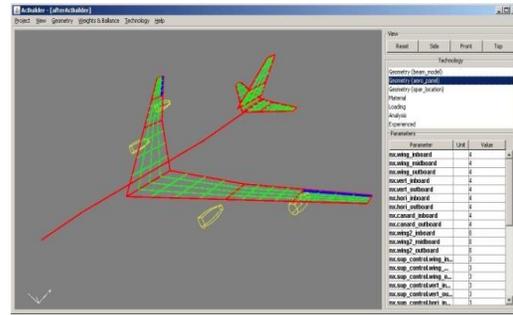


Figure 7. Technology Definitions [4]

2.1.2 SUMO

SUMO is a graphical tool aimed at rapid creation of aircraft geometries and automatic surface mesh generation developed by Larosterna [8]. It is not a full-fledged CAD system, but rather an easy-to-use sketchpad, highly specialized towards aircraft configurations. It is written in C++. It is designed for a simple & time saving surface modeling of different aircraft configurations. There are two surface types which simplifies the modeling. On the other hand user can define a body surface, e.g. for fuselage structure or pylons. On the other hand wing surface can be chosen, which are used for instance for modeling the horizontal tail and lifting surfaces. With the help of SUMO a mesh file for CFD analysis [9] can be generated. A surface mesh & a volume mesh are realizable.

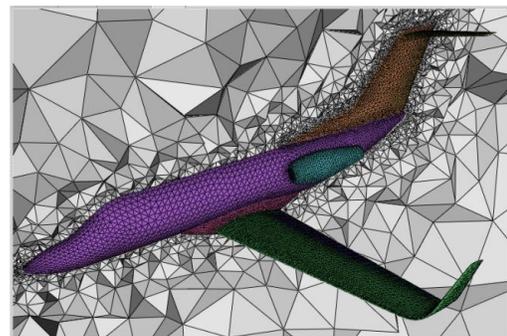


Figure 8. Mesh generated by SUMO[8]

2.1.3 AMB

The Aerodynamic Model Builder (AMB) controls the calculation and displays of the aerodynamic aircraft characteristics such the development of lift and drag over angle of attack. The user may currently choose between three methods. These are the vortex lattice solver Tornado, the empiric program Digital DATCOM of the US Air Force and the CFD flow solver EDGE of the Swedish Defense Research Agency FOI. In case EDGE is to be used as CFD solver a CFD mesh must be prepared using the tool SUMO previously.

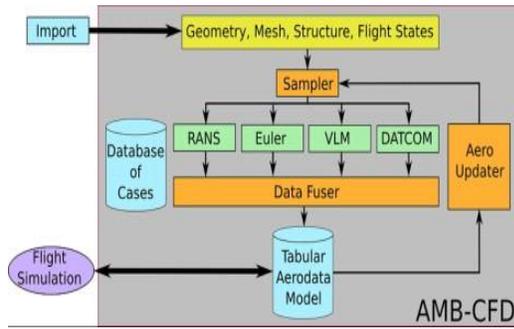


Figure 9. AMB Module [4]

Tornado and DATCOM do not require a detailed mesh, thus these solvers may be run directly after AcBuilder. Both are summed up under Tier 1 methods [10] & give good results for low speed aerodynamics & low angles of attack. The second fragment is based on the EDGE Euler code & belongs to Tier 1+[10]. Here the compressible effects are captured & hence used for high speed aerodynamics. A third part is Tier 2; it is not yet implemented to CEASIOM. It includes RANS flow simulation. ANS models include also viscous effects. A challenge is to approach automatic volume mesh generation for tier I+, with geometries including control surface deflections.

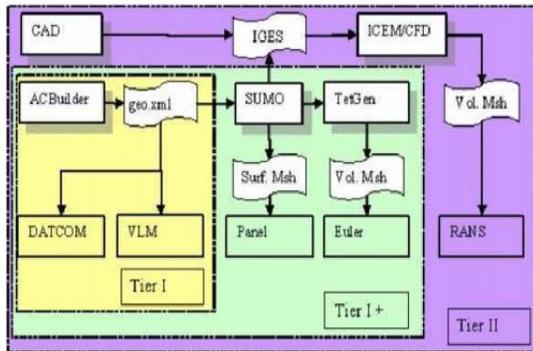


Figure 10. Adaptive Fidelity Geometry Modeling [10]

2.1.4 Propulsion

The Propulsion [11] tool calculates engine performance data over Mach number and altitude that are required for the following tool SDSA. The user interaction is limited to the input of the desired calculation nodes in terms of Mach number and altitude (in km).

2.1.5 SDSA

The SDSA [4] (Simulation and Dynamic Stability Analysis) module is useful for dealing with stability analysis based on JAR/FAR, ICAO & MIL. Also six degree of freedom simulation is possible. SDSA covers the following functionalities:

- Stability analysis: Eigenvalues analysis of linearized model in open and closed loop case and Time history identification (nonlinear model).
- Six Degree of Freedom flight simulation: Test flights, including trim response and Turbulence.
- Flight Control System based on Linear Quadratic Regulator (LQR) theory, including Human Pilot model, Stability Augmentation System and Actuator model o LQR based FCS.
- Performance prediction.

The core module of SDSA [12] is stability analysis. In Fig. the scheme of stability analysis is pictured. The mathematical model is transferred into matrix form for getting the result. SDSA includes two ways of transforming the nonlinear equation into a linear one. One possibility is making additional assumptions (e.g. that altitude angles are small). The second way is the direct linearization of the force vector by calculation of Jacobin matrix for the defined state of flight.

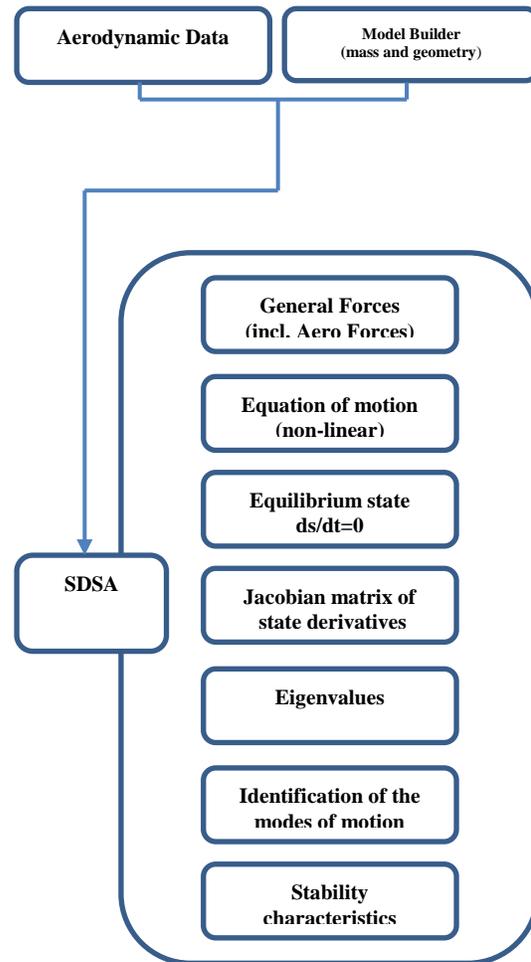


Figure 11. Stability analysis scheme

Next module is flight simulation model. With the help of this module it is possible to compute flight parameters in real time. In this way stability characteristics can be verified using a full nonlinear model.

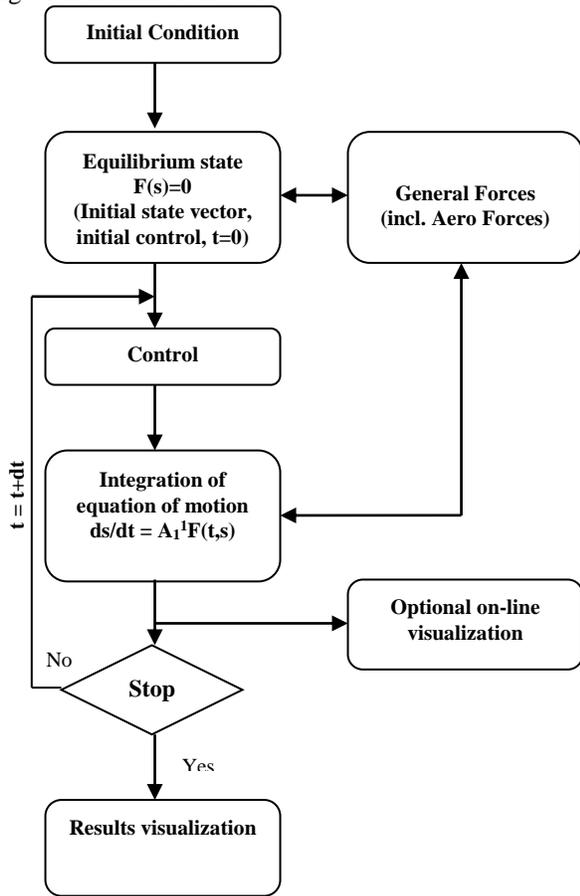


Figure 12. Scheme of Flight Simulation

The SDSA tool also include flight control system, which consists of a human pilot model, a stability augmentation system, an actuators model and a stabilization system based on LQR method.

2.1.6 NeoCass

NeoCass^[13] is a suite of modules that combines state of the art computational, analytical and semi-empirical methods to tackle all the aspects of the aero-structural analysis of a design layout at conceptual design stage. It includes two^[14] main modules, respectively named GUESS (Generic Unknowns Estimator in Structural Sizing) and SMARTCAD (Simplified Models for Aero elasticity in Conceptual Aircraft Design) as shown in figure 1. An external module is included, called W&B^[7] (Weight and Balance), used also by other modules of CAESIOM procedure, necessary in order to have a first estimate of the non-structural masses and their location for the estimation of inertial loads.

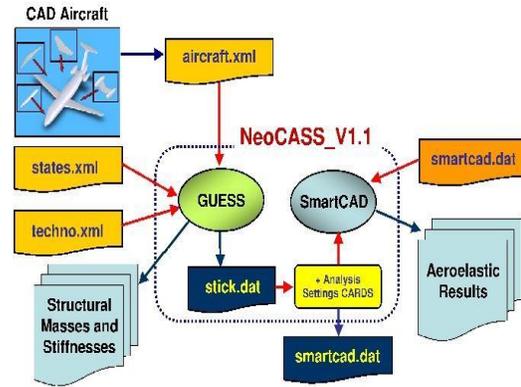


Figure 13. The layout of NeoCass Suite^[14]

In order to start the aero elastic analysis, a semi-analytical module named GUESS^[15] (Generic Unknowns Estimator in Structural Sizing), based on a modified version of the AFaWWE code (Analytical Fuselage and Wing Weight Estimation), is run to produce for the whole airframe an initial estimate of the stiffness distribution on the basis of user-defined sizing parameters. The initial structural sizing is performed in a fully stressed design condition and introduces structural instability limits for compressed panels and stiffeners. However, no aero elastic effects are considered during this sizing phase. Once the initial structural sizing and the first stiffness distribution is determined by GUESS, a structural and aerodynamic mesh is automatically generated to allow for the subsequent aero elastic assessment and optimization together with all the requested information for the fluid-structure interfacing.

The second main module is named SMARTCAD (Simplified Models for Aero elasticity in Conceptual Aircraft Design)^[16] and it is dedicated to the aero elastic analysis. SMARTCAD is based on different analysis tools with increasing fidelity and computational costs. Two classic lifting surface methods are implemented: the Vortex Lattice Method (VLM) for subsonic steady aerodynamic and aero elastic calculations and the Doublet Lattice Method (DLM) for the prediction of harmonic aerodynamic generalized forces and subsonic flutter analysis. An interface to high-fidelity CFD codes is also available. Since at the conceptual level indeed, the primary focus is on determining and representing at least structural/nonstructural mass and stiffness distribution to satisfy strength, stiffness and stability requirements. Few simple lumped structural elements capable of giving equivalent structural behavior can be used for this purpose such as a linear equivalent plate, linear beam or non-linear beam to introduce geometrical non-linear effects. These models lead to low-order algebraic problems, keeping the computational cost very low and allowing several configurations to be examined quickly. NeoCASS includes also a dedicated Multi-Disciplinary Optimization (MDO)

tool ^[17] used to refine the initial structural sizing so that different aero elastic constraints can be satisfied as limits on: divergence speed, aero elastic aerodynamic derivatives, maximum deformed shape under loading due to structural flexibility, flutter speed.



Figure 14. Examples of aircraft configurations that can be analyzed using NeoCASS: a small size trainer (left), a twin engine regional aircraft (middle) and a transonic cruiser (right).

2.1.7 FCSDT

FCSDT^[18] (Flight Control System Design Toolkit) has two main capabilities: The first function is to design the FCS itself while the second function is to perform some analyses which affect design of other sub-spaces in the aircraft design space. The FCSDT includes five modules known as: FCSA- Flight Control System Architecture, SCAA- Stability & Control Analyzer & Assessor, LTIS- Linear Time Invariant Synthesis, CLD-Control Laws Definition, FSim-Desktop Flight Simulator.

Under FCSA the architecture of control system is built up. The control system is the base for reliability analysis. The results of FCSA are given as files of the designed architecture, the bill of material & the failure mode. Also global live data for SCAA and FSim and graphical results are available. The SCSA tool includes functionality to trim, linearizing and simulating a Simulink built aircraft model. First the model is initialized, then the condition are set for trim and performance analysis. At last the trimming process and the simulation can be carried out. By LTIS tool flight control laws can be designed. Also closed loop system can be simulated and analyzed. The CLD module is based on the different aircraft control philosophies in various flight phases and maneuvers, built up by different parameters. It is possible to set and categorize the control laws and protections. FSim should be able to make a flight simulation according to the data from the FCSA tool.

3 Conclusions

CEASIOM uses AcBuilder to define the geometry of the aircraft and thus generate the input file for the other modules (i.e. AMB, NeoCass, FCSDT etc.). Hence a

precise output from the AcBuilder is the prerequisite for a successful iteration. And unfortunately CEASIOM acknowledges some degree of limitations at this regard. Limitation on aircraft configuration (since a CEASIOM aircraft must have a circular section on fuselage and at least a wing.) is often addressed while using AcBuilder. Besides, instead of limited to current proprietary *.xml format, users often prefer to adopt a more common data format and geometry. To mitigate such kind of problems defined by the users CEASIOM continues a dynamic evolution process. Some important ongoing developments are: new Graphical User Interface (GUI) for AcBuilder, a new version of AMB is under finalization, GUI optimization. At the end when the limitations are compromised CEASIOM offers a fast and up-to a certain degree of reliable computational method which replaces real life model analysis during conceptual design and saves time and simultaneously reduces product cost.

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References

- [1] CEASIOM, www.ceasiom.com.
- [2] www.simsacdesign.org.
- [3] Raymer, D.P (2006), Aircraft Design: A Conceptual Approach (4TH edition), Washington, DC, AIAA, Inc.
- [4] <http://www.ceasiom.com/ceasiom-modules.html>
- [5] Andrés Puelles et al, "CEASIOM XML file Definition", Royal Institute of Technology, Stockholm, February 2010.
- [6] Martin Lahuta," AcBuilder –input tool for CEASIOM software."
- [7] Javier Muñoz," CEASIOM Weight & Balance Module", KTH University,Stockholm, June 2010.
- [8] <http://www.larosterna.com/>.
- [9] A. Rizzi, J. Ooppelstrupy,M. Zhangz and M. Tomacx," Coupling Parametric Aircraft Lofting to CFD & CSM Grid Generation for Conceptual Design", 2011 AIAA Aerospace Sciences Meeting.
- [10] Molitor, P.: "CEASIOM tier 1 and 1+ module for simulation of aircraft stability and control characteristics", Stockholm, 2009.

[11] Kolja Seeckt, "Application of PreSTo: Aircraft Preliminary Sizing and Data Export to CEASIOM", Stockholm, Sweden, 2011.

[12] SimSAC, "SDSA-Theoretical Basics", Stockholm, Sweden, 2009.

[13] <http://www.neocass.org/>

[14] L. Cavagna, A. Da Ronch, S. Ricci, "NeoCASS Next generation Conceptual Aero Structural Sizing", Dipartimento di Ingegneria Aerospaziale - Politecnico di Milano.

[15] Da Ronch, A., "GUESS: Generic Unknown Estimator for Aircraft Structural Sizing," Master Thesis, Royal Institute of Technology (KTH), Stockholm, Sweden, October 2008.

[16] L. Cavagna, S. Ricci, and L. Travaglini. "Neocass: An integrated tool for structural sizing, aeroelastic analysis and mdo at conceptual design level." *Progress in Aerospace Sciences*, 47(8):621–635, 2011.

[17] L. Cavagna, S. Ricci, and L. Travaglini. "Aeroelastic analysis and optimization at conceptual design level using neocass suite", In *Proceedings of the 52th AIAA/ASME/ASCE/AHS/ASC SDM Conference*, Denver, Colorado, April 2011.

[18] Maheri, A.; Beaverstock, C.; Sidoryuk, M. "Flight Control and System Designer Toolkit-Technical Report and User Manual", Bristol: SimSAC, 2008.