CEAS
4:th CEAS Air & Space Conference
FTF Congress: Flygteknik 2013

Preliminary Design for Flexible Aircraft in a Collaborative Environment

Pier Davide Ciampa, Björn Nagel
German Aerospace Center (DLR), Germany

Darwin Rajpal, Gianfranco La Rocca
Delft University of Technology, The Netherlands

Keywords: *CPACS, Collaborative Design, DEE Initiator, Aeroelastic Engine, OAD*

Abstract

The work presents a collaborative design approach, developed to account for the structure flexibility effects in the pre-design stages of generic aircraft configurations. A streamlined design process is developed between DLR and TU Delft, to support the transition from an initial aircraft conceptual solution, to physics based simulations. The TU Delft DEE initiator is the conceptual tool providing the initial design, which is used to instantiate further analysis tool. An Aeroelastic Engine module is responsible for the abstraction of the aircraft structural properties, and the generation of the fluid-structure disciplinary couplings, necessary to account for the flexibility effects. Multiple distributed disciplinary solvers are available, and accessible via a decentralized architecture. All the analysis modules are integrated in the design workflow by means of the open source distributed framework RCE, and the DLR's central data model CPACS. The approach is tested for the pre-design of a conventional aircraft and a box-wing configuration, designed for a set of top level aircraft requirements. Hence, the flexibility effects for both cases are presented. The results demonstrate the importance of accounting for the flexibility effects already in the pre-design phase, especially in case of box-wing configurations, where difference in design performance can occur when ignoring such effects.

1 Introduction

The current visions and technology roadmaps on the future of the air transportation systems pose ambitious challenges for the design of the next generations' air vehicles [1, 2]. However, the assessment of game-changing technologies cannot rely on the conventional pre-design methodologies, which are primarily based on statistical data, and on the application of technology factors to account for potential benefits. Thus, in order to correctly assess the vehicles' behavior and performance, and to minimize the risks associated with the development of unconventional aircraft configurations, physics based simulations have to be included in the early stages of the design process.

Nevertheless, the sophisticated physics based analysis codes currently available in every aeronautical discipline, can be effectively used at the early stages, only if highly automated in the model pre-processing, analysis execution and post-processing of the results.

As identified in Ref.3, automated analysis capabilities relief the designer from allocating significant part of the development cycle to repetitive and non-creative tasks, and enable the large design space exploration required by unconventional designs.

However, state of the art aircraft pre-design systems are often based on automated, but monolithic design codes which cannot easily be managed, or adapted to cope with new configurations, or as new analysis modules become available [4]. The challenge is even higher if analysis modules developed by different parties are planned to be integrated within the same design process.

Further, as soon as the interdisciplinary dependencies are accounted into the design process, the application of MDAO (Multidisciplinary Design Analysis and Optimization) techniques can support the designers to correctly capture the overall aircraft's behavior. However, the introduction of physics based models into MDAO applications demands for disciplinary expertise within the aircraft design process, and for the cross-disciplinary consistency of the analysis models.

In order to cope with the mentioned challenges, DLR is developing a design environment to enable collaborative MDAO applications, within multiple internal projects [5], and with external institutions as well [6, 7].

This paper presents the implementation of a streamlined collaborative OAD (Overall Aircraft Design) process, which makes use of the design and analysis capabilities distributed between DLR and TU Delft, in order to support physics based simulations of conventional and unconventional configurations, already in the pre-design phase.

Among the many tools and disciplines involved in the process, the proposed design system includes a dedicated tool account for the flexibility effects due to the aero-structural interactions, already at the conceptual and preliminary design stages. In fact, although well-established methods are available for linear aeroelastic analyses of modern airplanes, there is still a limited capacity to bring them into the early stages of the design process [8]. Typically the postponed assessment of these effects to the later design stages, adds an "aeroelastic penalty" to the final designed structure [9, 10], and it may even lead to a complete redesign process for novel aircraft. One of the goals of this work is to assess the effect of accounting the flexibility effects in the early design phase, which, as discussed in Section 4, are particularly significant in case of unconventional aircraft such as box-wing configurations.

The integration of the disciplinary modules, such as the aerodynamic and the structural solvers, and the coordination of the workflow governing the fluid structure interactions, is implemented by making use of a centralized data model CPACS (Common Parametric Aircraft Configuration Schema), and the DLR open source framework RCE (Remote Computer Environment).

A brief introduction to the collaborative design environment architecture and to the central data model CPACS is provided in Section 2. The design and analysis components are presented in Section 3. Section 4 describes the application of the process for two test cases, a conventional and a box-wing aircraft configuration and discusses the results. Conclusions and outlook are provided in Section 5.

2 Collaborative Design Environment Architecture

Distributed design approaches [13] offer the flexibility to adapt the design workflow, when new design modules become available, and to tailor the scope of the design investigation. The German Aerospace Center (DLR) has been developing a decentralized design environment to foster the collaboration among disciplinary specialists and the integration of disciplinary expertise into a collaborative overall aircraft design process. The design environment is built on the central data model CPACS (Common Parametric Aircraft Configuration Schema) [11, 12], an arbitrary number of analysis modules, and on the open source design framework RCE (Remote Component Environment) [13], enabling the orchestration of the design workflows.

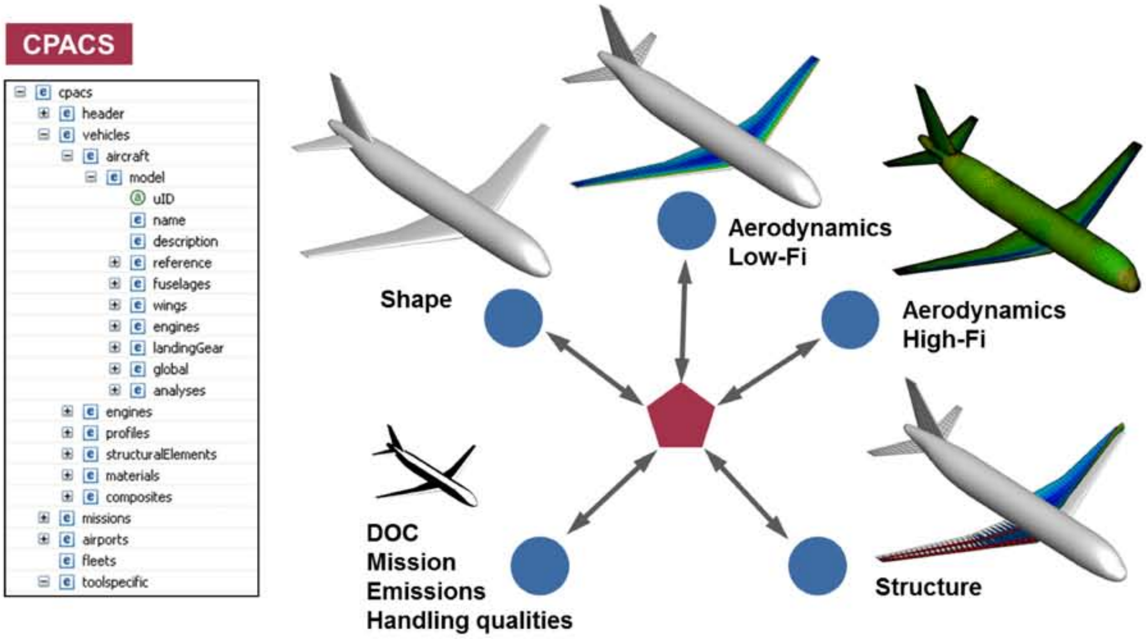

Fig. 1 CPACS (Common Parametric Aircraft Configuration Schema) concept.

CPACS is a data format based on XML technologies, and used for the interdisciplinary exchange of product and process data between heterogeneous analysis codes and name spaces. CPACS contains data such as the geometry of the aircraft model, but also all the parameters needed to initialize and to drive the disciplinary analysis modules, for instance the aerodynamic and the structural solvers. Figure 1 depicts the CPACS concept as a unique data structure, instantiating the disciplinary analysis modules.

The framework RCE enables the orchestration of the design process, and integration of the analysis modules in a workflow. The RCE architecture is based on a decentralized computing system, in which the analysis competences are hosted and run on dedicated servers. Thus, in the design workflow only input and output data are made accessible to the integrator designer, and exchanged during the process, whereas the source codes are controlled by the tools' developers and the disciplinary experts. The system is in operational use in all the DLR aeronautical branches [14, 15], and with external research and academic institutions [6, 31].

3 Overall Aircraft Design (OAD) of flexible aircraft

Typically, during the conceptual aircraft development, many design details are not available, and the overall aircraft synthesis relies on the definition of TLAR (Top Level Aircraft Requirements), such as transportation mission and operational constraints, and on the output of overall aircraft parameters, such as MTOW (Maximum Take Off Weight), aerodynamics efficiency, etc. [16, 17]. Nevertheless, the actual blending of the pre-design activities into the conceptual phases is pushing the development of more sophisticated conceptual design engines, which are capable to instantiate models with number of details beyond the typical conceptual stages [18,19]. Nevertheless, including physics based aeroelastic analyses in these early stages, has to cope with the challenge to generate the appropriate analysis models in a time efficient manner, and guarantee the automated couplings among the heterogeneous disciplinary abstractions.

Further, the shift to physics based analysis at the beginning of the design cycle is associated with the increase of the "aircraft modeling complexities" [20], typically leading to an increased number of the design variables, and a higher domain expertise required to set up the analysis parameters.

Hence, in an OAD application the designers' team faces the following challenges:

- Generation of an initial design, with a sufficient quality, and details, to serve the instantiation of further physics based analysis modules
- Automate the setup of an increased number of parameters, and design variables, associated to execution of the physics based analysis modules;
- Handle and setup consistent disciplinary couplings in MDAO applications, for a multitude of heterogeneous analysis tools.

The aforementioned challenges depend on the complexity of the modeling, and on the physics phenomena representation supported by the disciplinary analysis. Hence the following disciplinary levels can be identified:

- level 0: consisting of typical conceptual OAD approaches, based on empirical relations, and existing databases [16, 17];
- level 1: refers to disciplinary analysis based on simplification on the modeling, and on the representation of the physics phenomena, mainly accounting for linear effects;
- level 2: refers to an accurate modeling of the aircraft components, accounting for a higher level of details, and physics representation accounting for non-linear phenomena;
- level 3: refers to the state of the art of physics simulations, mainly dedicated to non-linear local effects, and whose disciplinary models cannot be fully automated, as required for extensive MDAO applications.

The introduced levels classification is indicated in Table 1, with focus on the aero-structural applications.

Table 1 Disciplinary Levels Classification

Level	Aerodynamics	Structures
L0	Empirical performance estimation	Handbook masses estimation
L1	Subsonic analysis (VLM, Panel method)	Simplified models (FEM beam)
L2	Transonic nonlinear analysis (Euler)	Detailed models (FEM shells), non-linear analysis
L3	Nonlinear non automated (RANS)	Nonlinear local analysis (buckling, crash)

The current study focuses on the integration of L0 and L1, in OAD as a blended conceptual and preliminary design stage. The TU Delft DEE Initiator module is used to generate an initial design synthesis, providing a limited number of top level aircraft requirements. Hence the initial design is coupled via the CPACS format to the physics based modules, such as the aerodynamics and the structural solvers, whose results are integrated into the aircraft synthesis process, till convergence.

The next sections introduce the main aforementioned design modules.

3.1 DEE Initiator

The DEE Initiator [18] is a MATLAB based conceptual design tool able to generate a baseline aircraft configuration, starting from a limited set of top level requirements, such as payload size and arrangement, range, cruise speed, takeoff and landing field length. Apart from conventional turboprop and turbofan aircraft, the Initiator can deal with some non-conventional aircraft configurations, such as box-wing aircraft and blended wing bodies. This is a clear distinctive feature, which makes the Initiator different than any other commercial conceptual design tool currently available on the market.

The Initiator implements some of the classical aircraft synthesis methods available in literature, but integrates and supports them by means of simple geometry models generated on the fly, a vortex lattice aerodynamic simulation tool and an optimization toolbox. These "extra ingredients" make the design process much less dependent on statistics and allow addressing other concepts than conventional aircraft. As shown in Fig.2, the Initiator mainly consists of an initialization module, a geometry model generator, some analysis modules and an optimizer. The "Initiator's initiator", called Initializer, has the task of deriving a first aircraft guesstimate, based on pure statistical data. To this purpose the Initiator can automatically access a large and extensible aircraft data base, which includes also data of non-conventional aircraft configurations extracted from design studies available in literature.

Before proceeding with any further analysis, wing loading and thrust weight ratio are automatically adjusted using an optimization routine, to make sure the aircraft design point satisfies typical top level requirements, such as takeoff and landing field length, climb rate and gradients at OEI conditions, etc.

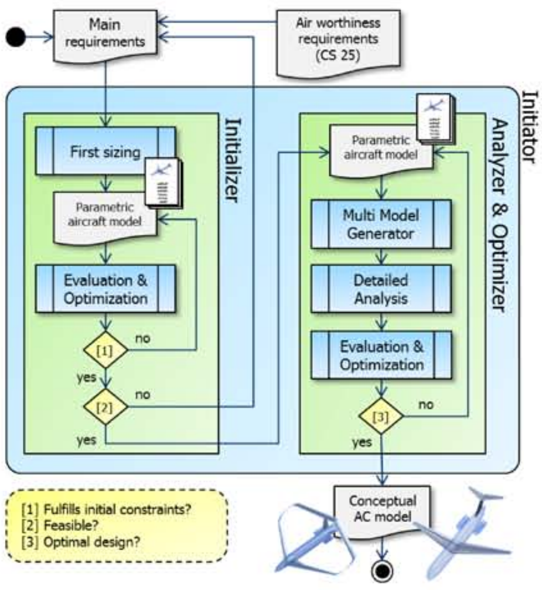

Fig. 2 DEE Initiator structure.

The Initiator geometry modeler is able to create simple aircraft models, where volumes, areas, distances, etc., can be extracted and used as input for the implemented semi-empirical analysis and sizing methods.

In particular, these geometry models are used to feed TORNADO, an open source vortex lattice method (VLM) suitable for conceptual design purpose. Although TORNADO is a low fidelity analysis tool, it allows the Initiator to account on more physics based aerodynamic results than those otherwise assumed based on statistics and generally only valid for conventional aircraft configurations.

A genetic algorithm optimizer has been developed on purpose to endow the Initiator with robust optimization capabilities. The Optimizer allows the designers to assess the impact of various objectives and constraints on the final design of the aircraft and its performances. The optimizer and the VLM tool are particularly useful for the initial sizing of joined-wing systems, where the relative positioning of the front and rear wing and their relative lift distributions need to be properly set to achieve proper stall behaviour and exploit the Prandtl's best wing system concept for minimum induced drag [21].

Some other of the Initiator analysis modules include a class I and class II weight estimation tool, a module for parasite drag estimation and a module for stability & control.

The Initiator can be operated both interactively, via an advanced GUI, and in batch mode. The latter functionality enables the Initiator to be integrated and operated via any workflow management system, such as RCE. Functionalities are in place to export all the generated values (geometry, weights, performance parameters, etc.) in form of Excel tables, or other formats, such as the CPACS described in the previous section.

In this study, the Initiator has been used to generate, starting from a set of top level requirements, two aircraft configurations: one conventional and the other featuring a box-wing system. The generated geometrical models for these types of configurations are shown in Fig.3. The models are thus exported into CPACS format, and can be used to initiate the higher fidelity design and analysis process which is described in details in the next sections.

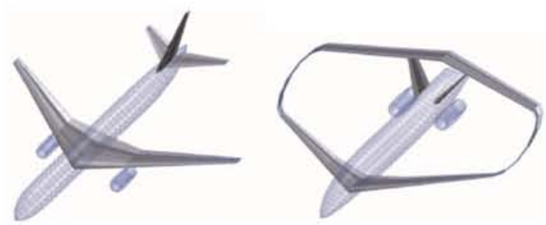

Fig. 3 Geometry models generated by the Initiator for a conventional and a joined-wing aircraft.

3.2 Physics based aeroelastic analysis

As soon as an initial design point is available, the model is advanced to the Aeroelastic Engine, a module developed to support the modeling and the analysis of the complete flexible aircraft for preliminary MDAO applications in a collaborative environment [22, 23]. The module provides hierarchy of physics based disciplinary models for the aeroelastic analysis, and supports the generation of the disciplinary couplings. Although complex analytical methods [24] exist for the structural analysis in the pre-design phases, the proposed investigation is based on the use of Finite Element (FE) representations to cope with unconventional designs. First function of the Aeroelastic Engine is to extract the structural properties that are needed for the aeroelastic modeling of the aircraft. This process, identified as *aeroelastic abstraction*, is dependent on the level of details of the disciplinary analysis involved in the modeling and analysis step. As a Level-1 model, the Aeroelastic Engine initializes the structural layout of the primary structures, extracts the structural properties of the complete aircraft, and finally assembles a multibody FE representation, based on a beam formulation. The primary structures of the lifting surfaces and of the fuselage components are identified, and beam's cross sectional properties (e.g., flexural and torsional stiffness) are derived from the geometry and from the explicit definition of the wingbox layout and fuselage's frames. Substructures, such as stiffeners, are taken into account by a smeared stiffness approach [25]. Figure 4 shows the assembled FE level-1 model produced by the module, for a conventional aircraft.

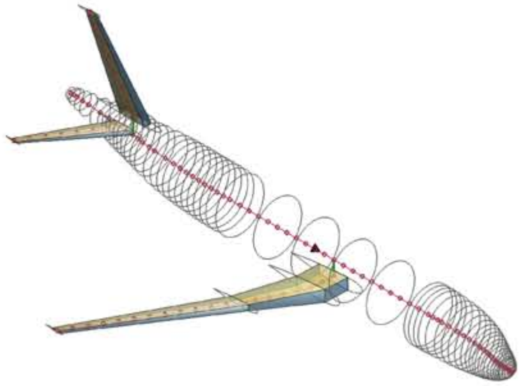

Fig. 4 Aeroelastic Engine FE level-1 Model Abstraction.

The level-1 formulation is part of a hierarchical set of models available for pre-design activities, which can be extracted from a unique centralized model definition [20, 26]. The Aeroelastic Engine provides an internal solver for the FE analysis and post-processing of the assembled models, in order to determine the displacements and the stress fields of the aircraft under multiple load cases. A number of sizing strategies, such fully stress design, and flexural buckling criteria, are implemented for the dimensioning of the selected primary structures.

3.3 Flexibility effects

In order to account for the aircraft flexibility effects, the fluid-structure interactions (FSI) need to be considered in the aero-structural analysis and sizing process. The aero-structural coupling is implemented by first mapping the aerodynamics forces on to the structural model, and then transferring the computed displacements on the structural nodes to the aerodynamic geometry. In a collaborative environment, loosely coupled analysis tools, such as the ones for the aerodynamics and for the structural analysis, are generally employed, with the consequent challenge of automating the generation of the necessary coupling links. The Aeroelastic Engine employed in this research is designed to accelerate the integration of the aero-structural discipline models by automating the required coupling operations on the base of the fidelity of the aerodynamic and structural solvers involved, and the setup of few parameters from the designer side. In the current study an available level-1 VLM aerodynamics tool, interfaced with CPACS [26], is used to estimate the aerodynamics efficiency at various conditions of the flight envelope, and to provide the aerodynamics loading distribution on the lifting surfaces, as resulting from the critical design maneuvers.

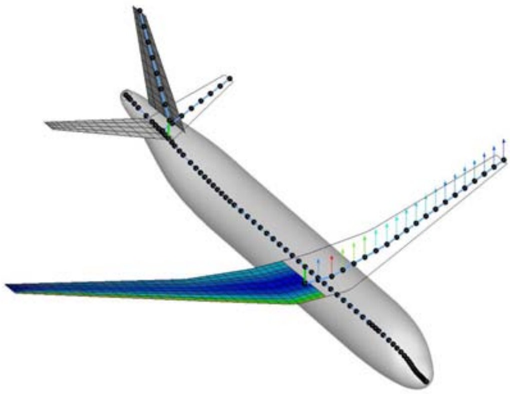

Fig. 5 FSI coupling provided by the Aeroelastic Engine. VLM lattice and pressure distribution (starboard), FE nodes, and nodal forces (port)

Figure 5 shows the results of overlaying the disciplinary models. The aerodynamics mesh and the calculated pressure distribution are shown on the starboard side of the aircraft; whereas the structural FE model is shown for port side. Further on the FE nodes of the main wing are shown the aerodynamics loads, as resulting from the mapping schema from the VLM lattice to the structural grid. Figure 6 shows the structural nodal displacements of the FE model due a test wing-fuselage loading case, and the propagation of the displacements on the geometry, via mesh deformation techniques available in the module, applied directly on the initial geometry, or on the disciplinary grid.

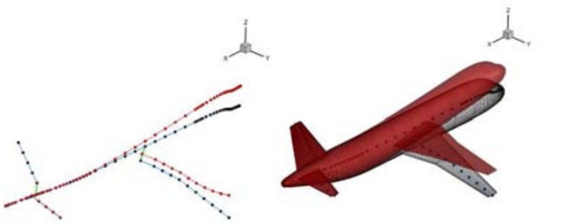

Fig. 6 a) FEA nodal displacements b) Aero-structural deformation propagated to the initial geometry.

The level of automation provided by the Aeroelastic Engine offers the possibility to iterate between the aero and the structural model, hence enabling designers to account for the flexibility effect in the early aircraft design phase.

4 Study cases

The next sections describe the implemented workflow, and two design cases. A tube and wings configuration, and a box-wing design have been selected to demonstrate the ability to address both conventional and unconventional configurations, when using physics based analysis tools.

4.1 Design Workflow

Starting with a minimum set of inputs, such as the transport mission requirements, the DEE Initiator module determines the initial estimation of the aircraft performance for the given design mission, such as the required fuel mass, and the aircraft dimensioning. Hence the initial design is forwarded to the physics based analysis modules, for the aero-structural sizing loop provided by the Aeroelastic Engine.

A 2.5 g pull-up maneuver is selected as critical loading condition, and the aero-structural sizing of the primary structures is performed under fully stressed design constraints, as typical of preliminary aircraft design. The use of the Aeroelastic Engines to size the wing allows to account for a physics based mass estimation.

The aerodynamic performance of the initial design is then calculated, accounting for the structure flexibility effect by means of the Aeroelastic Engine. The FSI coupling is taken into account to determine the lift and drag coefficients of the aircraft, for relevant combinations of angle of attack, Mach and Reynolds number. Hence, the updated aircraft aerodynamic performance, corrected by the flexibility effects, is used to update the overall aircraft design process, and the new aircraft synthesis computes new values of MTOW, and fuel weight. Hence, the design is reanalyzed through the physics based segment of the design process. The multifidelity synthesis loop will continue till the convergence of the design masses [28]. A schematic of the implemented workflow is shown in Fig.7.

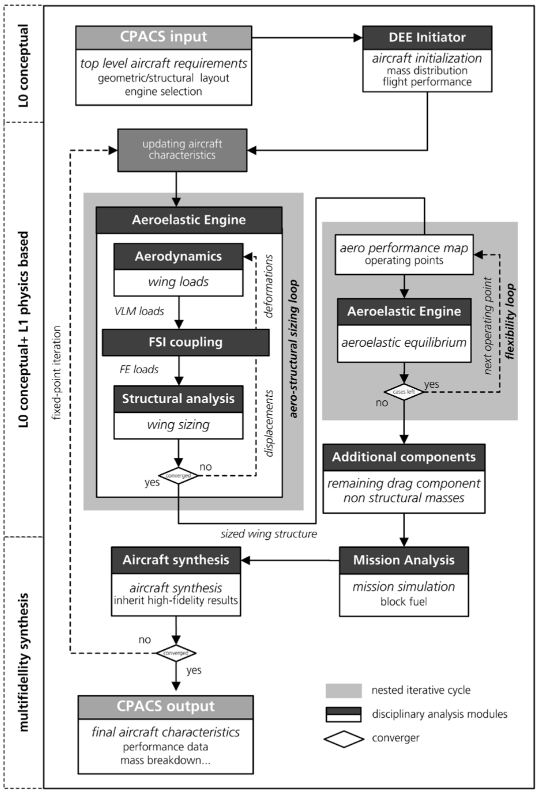

Fig. 7 Design process workflow.

The developed OAD workflow provides a significant level of flexibility, and can be executed with the following modalities:

- Only conceptual design, and excluding the physics based modules in the OAD synthesis: labeled as *L0 design process*;
- Conceptual and physics based design modules, whose analysis results are used to update the OAD synthesis. Although the aero-structural L1 solvers are employed for the structural sizing, the flexibility correction on the aerodynamic performance is excluded: labeled as *L0 + L1 Rigid design process*.
- Conceptual and physics based models, including the flexibility loop in the OAD synthesis: labeled as *L0 + L1 Flexible design process*.

In this, way the designer can tailor the process according to required level of accuracy and/or computational speed.

4.2 Conventional configuration

The conventional configuration is designed to satisfy the TLAR established for the collaborative design challenge, launched during the 2nd symposium on Collaborative Aircraft Design, held in December 2012 at DLR, Hamburg [29].

Among the others, the main mission's requirements are a design range of 2000 nm, at Mach 0.79, with 190 passengers. Although the set of TLAR is sufficient for the conceptual synthesis, additional tools' specific inputs are required for the other disciplinary modules, e.g. materials allocation, selection of the propulsion system technologies. Table 2 provides an excerpt of the design requirements, and other properties used for the aero-structural sizing.

Table 2 TLAR design challenge.

Parameter	Value
Design range (nm)	2000
PAX	190
Mach cruise	0.79
Initial climb	FL 350
Pull-up maneuver n	2.5
σ (MPa)	326
τ (MPa)	242

The overall aircraft synthesis is repeated three times: only conceptual design process (L0 level), conceptual and physics based (L0 + L1 level) with and without flexibility effects. Figures 8 shows the design solution as synthesized by the DEE Initiator, exported as CPACS format, and visualized by the CPACS geometry interpreter TIGLViewer [30]. Figure 9 shows the disciplinary models generated by the analysis tools, namely the aerodynamics VLM lattice for the lifting surfaces, and the FE beam model of the aircraft. The nodal deflections are also shown for the main wing, under the critical sizing load case. The results of the OAD process, such as the take-off mass (mTOM), and fuel mass (mFM), for each of the three synthesis cases, are reported in Table 3.

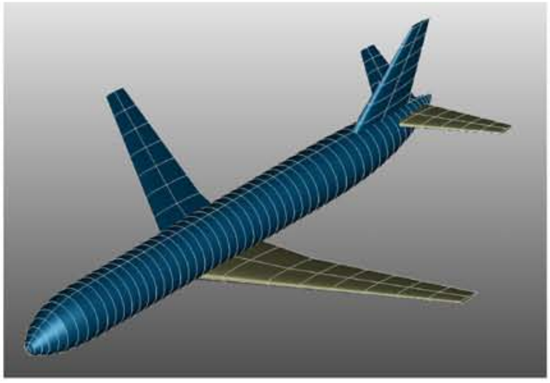

Fig. 8 CPACS Conventional aircraft generated by the DEE Initiator, as visualized in TIGLViewer.

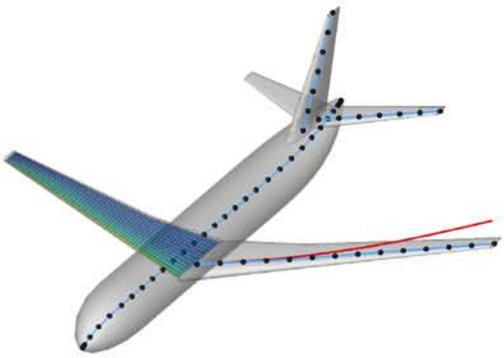

Fig. 9 Aeroelastic Engine VLM lattice (with pressure distribution) and structural model (with nodal displacements shape) of the initial conventional.

Table 3 OAD results Conventional configuration.

OAD	Conceptual L0	Conceptual L0 + Physics based L1	
	Initial	Δ^1 Rigid %	Δ^2 Flexible %
mTOM [kg]	83145.7	-13%	+1.5%
mFM [kg]	18947	-9%	+3%
OEM [kg]	45198	-17%	+1%

1: Δ% respect to initial OAD values
2: Δ% respect to rigid OAD values

The converged aircraft design masses show a difference between the L0 conceptual case, and the one including the physics based analysis. The main difference is in the operating empty mass (OEM) values, resulting by an under estimation of the computed structural masses. For a conventional configuration, conceptual design tools (L0) can provide very accurate results, since extensive database are available, and the synthesis process is calibrated on real aircraft data. On the other hand, physics based analysis would need to account for the simulation of a multitude of critical flight conditions and phenomena, to produce accurate results, without calibration factors. In the current chain a limited set of critical flight conditions, and failure criteria are taken into account, resulting in an under estimation of the sized structures. Nevertheless, the physics based chain enables the simulation of the aircraft physics behavior, by accounting for the deflected flying shape during the various mission segments. For an aircraft featuring a conventional swept-back wing system with moderate aspect ratio, the structural flexibility is known to result into a degradation of the aerodynamics performance respect to the rigid analysis [9], as shown as well by the results in Table 3. In fact the flexibility effect, when propagated through the OAD loop, generates an increase in fuel mass, and OEM in order to satisfy the defined TLAR.

4.3 Unconventional configuration

Additionally the described approach is applied for the analysis of a box-wing configuration. In order to have a reference model to evaluate the resulting designs, the set of TLAR is taken from an existing design from Ref. 30.

As for the previous design case, the aircraft is redesigned three times, using the different modalities offered by the implemented design systems.

Figure 10 shows the model generated by the by the DEE Initiator, and exported as CPACS.

Figure 11 shows the physics based analysis models, i.e. the aerodynamics lattice, and the FE model, and the wing system displacements produced by the critical loading condition.

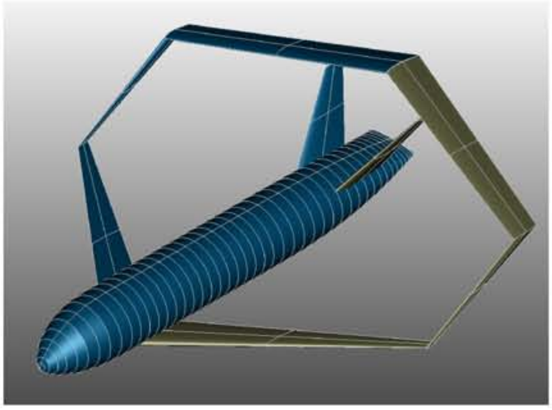

Fig. 10 CPACS box-wing aircraft generated by the DEE Initiator, as visualized in TIGLViewer.

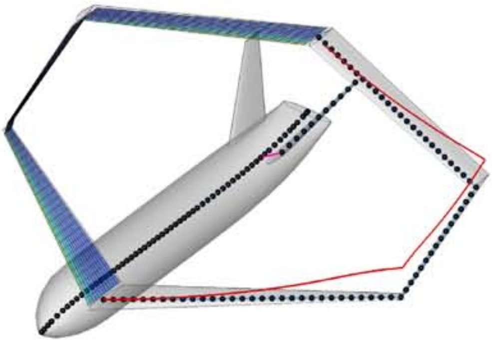

Fig. 11 Aeroelastic Engine VLM lattice (with pressure distribution) and structural model (with nodal displacements shape) of the initial box-wing design.

The results of the aircraft performance and converged design masses are shown in Table 4.

For this case the differences on the final design masses are very limited between only conceptual (L0 level), and the physics based case without flexibility (L0 + L1 rigid). The conceptual module includes in its database box-wing designs, whose data are the results of simulations as well, and it makes use of simplified physics calculation methods for the synthesis. Hence, the conceptual results are much closer to the results synthesis of the physics based approach. On the other hand, for this test case are more interesting the results when the flexibility effects are accounted in the OAD process (L0 + L1 flexible), which were not accounted for in the reference design. In contrast with the conventional case, the OAD synthesis of this specific box-wing design, results in lower design masses and fuel consumption when including the flexibility effects respect to the rigid analysis. It is necessary to point that the behavior of such a configuration is less predictable a priori by the designer, contrary to a cantilever wing type. Therefore, the aero-structural response could be design specific, and an extensive design space exploration using physics based analysis is required to generalize the exhibited trends.

Table 4 OAD results box-wing configuration.

OAD	Conceptual L0	Conceptual L0 + Physics based L1	
	Initial	Δ^1 Rigid %	Δ^2 Flexible %
mTOM [kg]	245551	+1.5%	-2%
mFM [kg]	77474	+1.3%	-2.8%
OEM [kg]	126327	+1.2%	-1.9%

[1]: Δ% respect to initial OAD values
[2]: Δ% respect to rigid OAD values

5 Conclusions and Outlook

The presented collaborative approach and the described design modules, aims at improving the conceptual/preliminary design process, for conventional and unconventional aircraft configurations. A physics based OAD process is developed by DLR and TU Delft, making use of distributed design modules, sharing the centralized parametrization CPACS, and connected by RCE framework. The proposed approach aims at enhancing the design process by accounting for the structure flexibility effects on the estimation of the aircraft performance and on the overall synthesis process. The proposed design approach is based on the use of the DEE Initiator, a conceptual aircraft design module capable to initialize also unconventional aircraft, and of the Aeroelastic Engine, a module developed to support loosely coupled aeroelastic analysis in collaborative MDAO applications. The assembled design system was tested for two design studies. The first study case, presents the OAD results of a conventional aircraft, designed to satisfy the TLAR specified in the collaborative design challenge.

Here the flexible effects have a marginal impact, and the degradation of the performance is expected by the designer. Further, the study highlights the complexities faced by the designer when introducing physics based analysis in the predesign stage.

The second case consists in the OAD of a box-wing configuration. For this design a purely conceptual approach is not sufficient to understand the aircraft physics behavior, and flexibility effects exhibit a large impact on the aircraft performance. Nevertheless, the shown response could be design dependent, and an extended exploration of the design space is necessary to capture and to generalize the trends. Further, only static aero-structural effects are accounted for in this study, and dynamic instabilities are expected to have a critical impact on the design results.

The proposed design process has shown to provide further insight into physics based modeling of aircraft at the early stages, and will be extended in future studies.

Additionally, the distributed approach contributes to the development of improved aircraft design methodologies, but also to the generation of a common, and understanding, between heterogeneous parties, on potential future aircraft configurations. A complementary study, making use of the developed design process, is presented in Ref. 33.

The synergy between the presented design competences is expected to increase in the next studies, encompassing additional design modules, and larger design space explorations, and optimization design cases.

Contact Details

Pier Davide Ciampa
German Aerospace Center (DLR)
Blohmstraße 18, 21079 Hamburg, Germany
Email: pier-davide.ciampa@dlr.de
Telephone: +49-40-42878-2727

References

[1] Report of the High Level Group on Aviation and Aeronautical Research "Flightpath 2050 Europe's Vision for Aviation", 2011.

[2] Strategic Research and Innovation Agenda (SRIA), Advisory Council for Aviation Reseacrh and Innovation in Europe (ACARE), 2012

[3] La Rocca, G., "Knowledge Based Engineering Techniques to Support Aircraft Design and Optimization", doctoral dissertation, Faculty of Aerospace Engineering, TU Delft, Delft 2011.

[4] Kroo, I., Manning, V., "Collaborative Optimization: Status and Directions", *8th AIAA Symposium on Multidisciplinary Analysis and Optimization*, Long Beach, 2000.

[5] Zill, T., Böhnke, D., Nagel, B., "Preliminary Aircraft Design in a Collaborative Multidisciplinary Design Environment", *AIAA Aviation Technology, Integration, and Operations (ATIO)*, Virginia Beach, 2011.

[6] Nagel, B., Böhnke, D., Gollnick, V., Schmollgruber, P., Rizzi, A., La Rocca, G., Alonso, J.J., "Communication in Aircraft Design: can we establish a common language?", *28th International Congress of the Aeronautical Sciences*, Brisbane, 2012.

[7] Pfeiffer, T., Nagel, B., Böhnke, D., Rizzi, A., Voskuijl, M., "Implementation of a Heterogeneous, Variable-Fidelity Framework for Flight Mechanics Analysis in Preliminary Aircraft Design", *German Aeronautics and Space Congress*, DLRK, 2011, Bremen, Germany.

[8] Livne, E., "Future of Airplane Aeroelasticity", *Journal of Aircraft*, Vol. 40, No. 6, 2003, pp. 1066-1092.

[9] Wright J. R., and Cooper, J.E, *Introduction to Aircraft Aeroelasticity and Loads*, AIAA Education Series, 2007.

[10] Howe, D., *Aircraft Loading and Structural Layout*, AIAA Education Series, 2004.

[11] Liersch, C.M., Hepperle, M., *"A Distributed Toolbox for Multidisciplinary Preliminary Aircraft Design", CEAS Aeronautical Journal*, Vol. 2, p. 57 – 68, Springer, 2011.

[12] http://code.google.com/p/cpacs.

[13] http://code.google.com/a/eclipselabs.org/p/rce/

[14] Nagel B., Zill, T., Moerland, E., Boehnke, D., "Virtual Aircraft Multidisciplinary Analysis and Design Processes – Lessons Learned from the Collaborative Design Project VAMP", *4th CEAS Air & Space Conference*, Linköping, Sweden, 2013.

[15] Moerland, E., Becker, R.-G., Nagel, B., "Collaborative understanding of disciplinary correlations using a low-fidelity physics based aerospace toolkit", *4th CEAS Air & Space Conference*, Linköping, Sweden, 2013.

[16] Torenbeek, E., Synthesis of Subsonic Airplane Design, Delft Univ Press, 1982.

[17] Raymer, D., Aircraft Design: A Conceptual Approach, 4th ed., AIAA Education Series (2006).

[18] La Rocca, G., Langen, T., Brouwers, Y., "The Design and Engineering Engine. Towards a

modular System for collaborative Aircraft Design", 28th International Congress of the Aeronautical Sciences, Brisbane, 2012.
[19] Rizzi, A., "Modeling and simulating aircraft stability and control The SimSAC project", Prog Aerospace Sci, Vol 47, 2011, pp.573-588.
[20] Ciampa, P.D., Zill, T., Nagel, B., "A Hierarchical Aeroelastic Engine for the Preliminary Design and Optimization of the Flexible Aircraft", *54th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference,* Boston, 2013
[21] Frediani A. "The Prandtlplane", *ICCES04, Tech Science Press*, Madeira, Portugal, 2004, pp. 19-31.
[22] Ciampa, P.D., Zill, T., Nagel, B., "Aeroelastic Design and Optimization of Unconventional Aircraft Configurations in a Distributed Design Environment", *53rd AIAA Structures, Structural Dynamics, and Materials Conference*, Honolulu, 2012.
[23] Zill, T., Ciampa, P.D., Nagel, B., "A Collaborative MDO Approach for the Flexible Aircraft", *54th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference,* Boston, 2013
[24] Ardema, M., Chambers, A., Hahn, A., Miura, H., and Moore, M., "Analytical Fuselage and Wing Weight Estimation of Transport Aircraft", NASA TR 110392, May 1996.
[25] Ciampa, P. D., Nagel B., and van Tooren, M. J. L., "Global Local Structural Optimization of Transportation Aircraft Wings", *51st AIAA Structures, Structural Dynamics, and Materials Conference 18th AIAA/ASME/AHS Adaptive Structures Conference*, Orlando, 12-15 April 2010.
[26] Nagel, B., Rose M., Monner H.P. and Heinrich, R., "An Alternative Procedure for FE-Wing Modelling", *Deutscher Luft- und Raumfahrtkongress*, Braunschweig, 2006.
[27] Rajpal, D., "Developement of Distributed MDO System for Non Planar Aircraft Studies", M.Sc. thesis, TU Delft, 2013.
[28] Böhnke, D., Nagel, B., Gollnick, V., "An Approach to Multi-Fidelity in Conceptual Aircraft Design in Distributed Design Environments", *32nd IEEE Aerospace Conference, Big Sky*, 2011.
[29] http://code.google.com/p/cpacs/downloads/detail?name=DesignChallenge.pdf
[30] http://code.google.com/p/tigl/
[31] Bottoni, C., Scanu, J., "Preliminary design of a 250 passenger PrantlPlane aircraft", M.Sc. thesis, University of Pisa, 2004.
[32] Boehnke, D., Nagel, B., Zhang, M., Rizzi, A., "Towards a Collaborative and Integrated Set of Open Tools for Aircraft Design", *51st AIAA Aerospace Sciences Meeting*, 07-10 January 2013, Grapevine, Texas.
[33] Ciampa P.D., Nagel B., Meng, P., Zhang, M., Rizzi A., "Modeling for Physics Based Aircraft Predesign in a Collaborative Environment", *4th CEAS Air & Space Conference*, Linkoping, Sweden, 2013.