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Christophe David, Scott Delbecq, Sebastien Defoort, Peter Schmollgruber, Emmanuel Benard, et al.. From FAST to FAST-OAD: An open source framework for rapid Overall Aircraft Design. 10th EASN International Conference, Sep 2020, Salerme, Italy. 10.1088/1757-899x/1024/1/012062 . hal-03182524

**HAL Id: hal-03182524**

**<https://hal.science/hal-03182524>**

Submitted on 26 Mar 2021

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To cite this article: Christophe David *et al* 2021 *IOP Conf. Ser.: Mater. Sci. Eng.* **1024** 012062

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# From FAST to FAST-OAD: An open source framework for rapid Overall Aircraft Design

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**Abstract.** To face the increasing environmental footprint of commercial aviation, industrial and research efforts have been focusing on exploring unconventional configurations and new propulsion paradigms, mostly based on electric technology. Such explorations require Overall Aircraft Design that has to be performed in an integrated multidisciplinary design environment. Such design environments are often limited to multidisciplinary analysis, adapted for a single aircraft configuration or require an important effort to be mastered. FAST-OAD is a software program developed by ONERA and ISAE-SUPAERO for aircraft sizing analysis and optimization that aims at user friendliness and modularity. It is an aircraft sizing code based on multidisciplinary design optimization techniques and the point mass approach to estimate the required fuel and energy consumption for a given set of TLARs. This paper presents the motivations for moving from the original software program, called FAST, to the open source code FAST-OAD based on OpenMDAO.

## 1. Introduction

To face the increasing environmental footprint of commercial aviation, industrial and research efforts have been focusing on exploring unconventional configurations and new propulsion paradigms, mostly based on electric technology. This has been reinforced by the unprecedented rush for urban mobility and more generally electric light aircraft, with similar societal expectations.

Overall Aircraft Design (OAD), the conceptual or preliminary level design process of an aircraft, requires integrating models representing the inherently multidisciplinary properties of such complex systems. The goal is to search for the best configuration that fulfills a given set of TLARs (Top Level Aircraft Requirements). In addition to commercial tools, universities or research institutes contribute to the development of tools or methods for OAD. At Linköping University a design framework is being developed to support the initial conceptual design phase of new aircraft and has been first presented in [1]. The University of Stanford develops SUAVE, a conceptual level aircraft design environment developed in Python to analyze and optimize both conventional and unconventional designs [2]. At the University of Michigan, the MDOLab focuses on the accurate and efficient computation of derivatives to aid gradient-based optimization methods and collaborates with NASA in the development of OpenMDAO [3], a framework to facilitate the application of Multidisciplinary design optimization (MDO). The MDOLab also provides a lightweight wing aero-structural optimization code [4].



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ONERA and ISAE-SUPAERO have an existing framework called FAST which has been used for the OAD of different configurations and architectures. The recent development of FAST-OAD aims at enhancing this legacy code as well as bridging the gap regarding modularity compared to FAST and other previously cited frameworks.

To explain the motivations and improvements for moving from FAST to FAST-OAD, the paper is organized as follows. Section 2 presents the architecture, models and applications of the legacy code FAST as well as its strengths and weaknesses. Section 3 explains the architecture, main developments and usages of the new OAD framework FAST-OAD. Finally, Section 4 provides concluding remarks and outlines probable future work.

## 2. FAST: Fixed-wing Aircraft Sizing Tool

### 2.1. Architecture

FAST is a software program initially developed in 2015 by putting together the expertise of ONERA in aerospace vehicle design studies and multidisciplinary analysis processes and the one of ISAE-SUPAERO in aircraft design teaching. The development was achieved using pure Python and aimed at delivering an aircraft sizing analysis code. The sizing code is based on the point mass approach to estimate the required fuel and energy consumption for a given set of TLARs. The resizing and positioning of components (in particular wing and tail surfaces) is automatically carried out. FAST is made up of specific modules for the key disciplines: Aerodynamics, Structure/Weight and Propulsion. Higher fidelity modules can be implemented thanks to pre-defined data models and the object-oriented capabilities of the tool. All data calculated in the disciplinary modules are lately used in the performance module which computes a full mission, using a time step integration method. FAST includes some OAD rules in order to size the empennage and place the wing and main landing gear. The outputs of FAST include various parameters of the aircraft (drag polars over the flight domain, engine deck, detailed mass breakdown, duration and fuel consumption of each flight phase,...) and estimated graphs of various in-flight parameters like Payload-Range diagram, flight path of a mission etc. FAST also includes a visualization routine which generates an OpenVSP file [5] to obtain a 3D model of the resulting aircraft. An overview of the multidisciplinary analysis process of FAST is shown in Figure 1.

FAST has been initially developed and validated on the specifications of an Airbus A320. The models used in FAST are mostly analytic, based on typical aircraft design literature as well as some in-house models. In addition, FAST implements a quasi-static model for mission and performance as well as low fidelity Computational Fluid Dynamic (CFD) for the low speed aerodynamic analysis. A functional description of these models are given by module:

- **Geometry**

- The fuselage geometry is estimated with respect to cabin layout (itself a function of number of passengers and layout parameters).
- A parametric geometry of lifting surfaces is used to have a limited number of degrees of freedom.

- **Aerodynamics**

- The friction drag is estimated through wetted area and friction coefficient correlations with respect to the Reynolds number.
- The induced drag is estimated through the Oswald coefficient which is a function of Mach number [6].
- Low-speed lift and drag coefficients are computed by using XFOIL [7] for clean wing configuration and through Raymer-type correlations [8] when flaps are deployed.

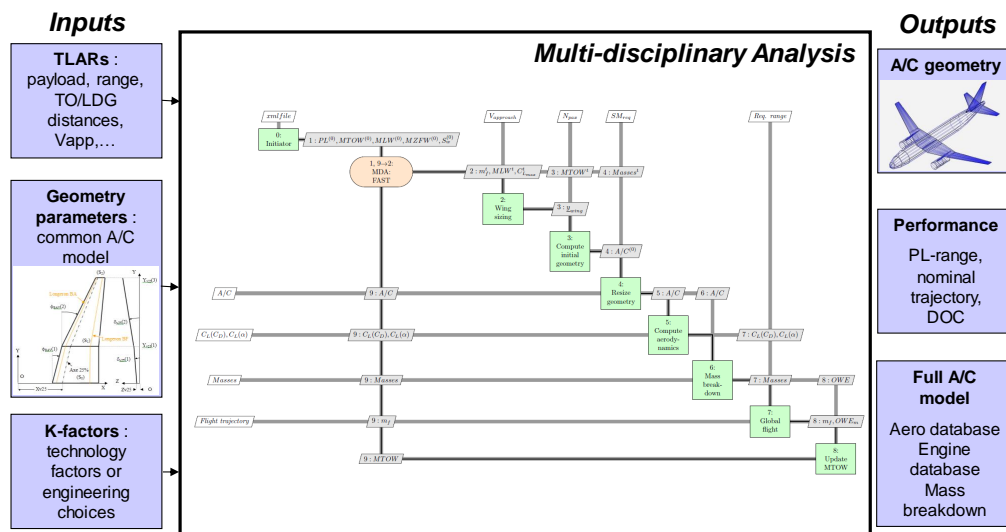


Figure 1. FAST overall architecture.

### • Weight

- The structural weights are computed with respect to simplified loads: gust at maximum and minimum weights.
- A collection of parametric empirical correlations is used for each structural component and on-board systems, enabling a detailed estimation of the Overall Weight Empty (OWE) for commercial aircraft.

### • Propulsion

- Implementation of a "rubber" engine which is scalable with respect to the Sea Level Static (SLS) thrust, ByPass Ratio (BPR), Overall Pressure Ratio (OPR), turbine inlet temperature, maximum take off (MTO) thrust, maximum Mach and design altitude [9].

### • Performance

- A time step integration approach is implemented for all the mission phases (main route and diversion).
- Different flight control strategies are implemented such as constant altitude, continuous climb and soon step climb.
- The full mission analysis can be replaced by a Breguet-Leduc range equation.

## 2.2. Sizing loops and multidisciplinary analysis

Most OAD problems contain multidisciplinary couplings that have to be solved to obtain a consistent design. In FAST, the multidisciplinary couplings are solved with numerical solvers providing a complete multidisciplinary analysis for the sizing of the vehicle.

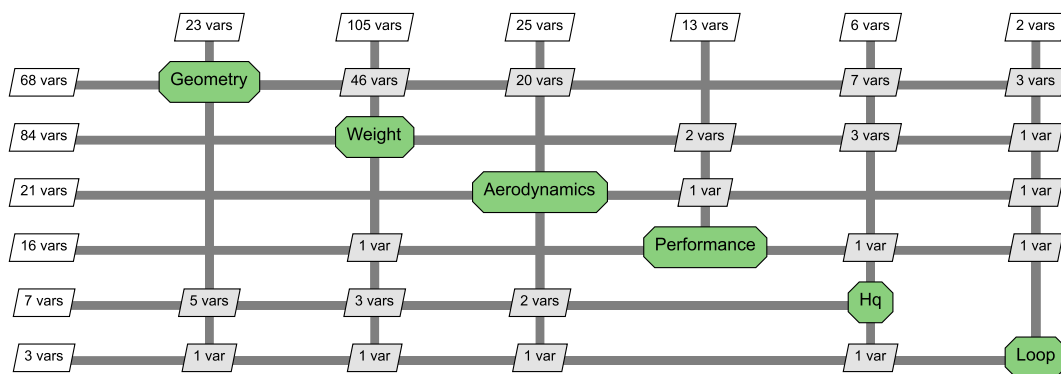
Figure 2 depicts the different multidisciplinary couplings, also referred to as sizing loops or algebraic loops, present in the OAD code.

The resizing block acts on the wing position, the main landing gear position, and sizing of the horizontal and vertical tail plane to have a design that verifies a static margin objective. This requires an aerodynamic analysis to determine the aerodynamic center and the weights analysis to determine the different mass used for the equilibrium.



**Table 1.** Strengths and weaknesses of the FAST sizing code.

Strengths	<ul style="list-style-type: none"> <li>• A code structure and MDA process that enables OAD</li> <li>• Usage of low fidelity models but lightweight and validated</li> <li>• The capability to connect different models including higher fidelity tools</li> <li>• The capability of addressing new configurations and technologies</li> <li>• The usage of Python for benefiting from scientific computing packages and to easily be interface with other tools</li> <li>• To have a free OAD tool that does not require commercial software</li> </ul>
Weaknesses	<ul style="list-style-type: none"> <li>• A lack of modularity (make switching/extending models easier)</li> <li>• Difficulties to integrate user defined MDO approaches</li> <li>• Limited capability to Incorporate more disciplines / system models</li> <li>• An unclear separation between software core and models</li> <li>• A thorough documentation of the code usage and models</li> </ul>

**Figure 3.** FAST-OAD disciplines interrelationships.

sense, the iPOPO framework (<https://github.com/tcalmant/ipopo>) has been used in order to develop a model management system.

The current beta release is limited to the tube and wings configurations with conventional turbofan propulsion, but further studies conducted at ONERA and ISAE-SUPAERO have proved the possibility to extend it towards a large set of aircraft design problems. The default vehicle provided in the open source version is a conventional commercial aircraft close to an Airbus A320. Most of the models used come from the legacy FAST but have been reorganized to increase computational performance and produce the same results. FAST-OAD is developed with high level standards and practices of software development in order to guarantee high quality code documentation and maintenance as well as pertinent examples and tutorials.

### 3.2. Main developments

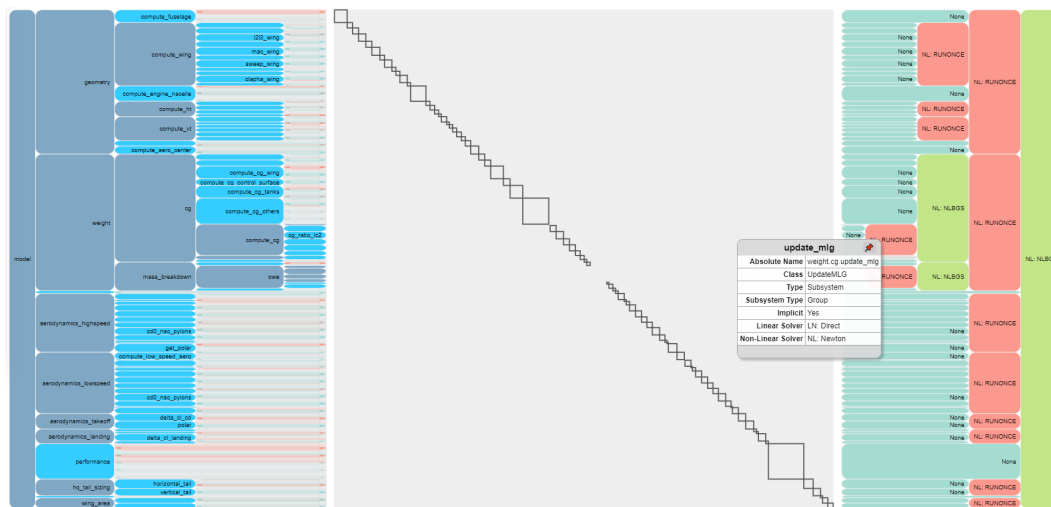
Once the analysis of the original code strengths and weaknesses, it has been an opportunity for the development of the open source version to tackle the identified weaknesses. Significant developments and progress between the two versions can be underlined.

The code and usage have now a clearer separation between software core and models. This allows to build synergies around the software code between projects that develop different vehicle codes and models. A significant effort was made to propose a new naming of variables which is



clearer and more generic. Also, the documentation of the code and the models has been achieved more thoroughly.

As mentioned previously, the models have been rewritten in order to match the OpenMDAO framework format and thus benefit from the capabilities and features that it offers. Indeed, this was the opportunity to define a new MDA strategy compared to the legacy code that used some fixed step iterative algorithms. It was chosen to implement a MultiDisciplinary Feasible (MDF) strategy with semi-analytic finite difference [15]. As shown in Figure 4, the internal sizing loops are solved using three nested non linear solvers (2 Non linear Gauss-Seidel and 1 Newton) and a non linear Gauss-Seidel solver for global convergence.



**Figure 4.** N2 diagram showing the MDA strategy with global and nested nonlinear solvers (grey=Newton, green=Gauss-Seidel).

This enabled to reduce by a factor 10 the computation time of an analysis. Furthermore, switching to OpenMDAO offers the possibility to perform optimizations which was absent of the legacy version.

The iPOPO-based model management system that was developed allows an easy integration of user defined models. It also enables to switch from one model to another as an answer to the identified lack of modularity.

Finally, it was decided to develop a minimalist User Interface (UI) in order to ease the pre-processing, execution and post-processing in the process. The strategy chosen was to use the Jupyter project (<https://jupyter.org/>) which provides Jupyter Notebooks, Jupyter Lab and widgets.

### 3.3. Usages and applications

The core file when working with FAST-OAD is the configuration file. It is where the used models are declared as well as the input file name requested by the computation process and the resulting output file name. It is possible to specify a reference file (e.g describing an existing aircraft) that will be used to set the values of the variables in the input file.

The user can use the Command Line Interface (CLI) or the Python Application Programming Interface (API) to:

- perform some pre-processing (e.g. generation of an input file containing the global input variables to be specified)
- obtain some model information (e.g. list of the models used and their documentation)



- execute the model (e.g. run an evaluation or an optimization)

This can also be achieved in a more user friendly manner using the minimal UI available when using Jupyter Notebook or Lab especially for viewing or modifying the values of variables. These offer also the possibility to use post-processing features such as a synthetic visualization of the optimization results, some useful plots as illustrated in Figure 5.

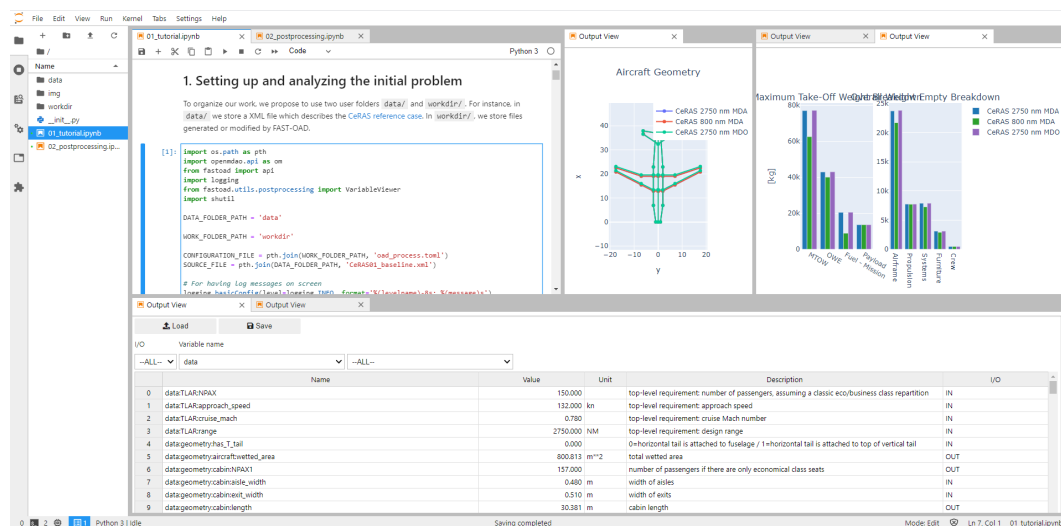


Figure 5. Example of JupyterLab deck for FAST-OAD.

The framework also provides some tutorial notebooks based on the example of the design of an Airbus A320 like aircraft. Further features, examples and applications will be added during the development of the framework. It is sought to use this framework with academic and industrial partners for addressing other configurations such as general aviation aircraft [16] and multirotor drones [17].

#### 4. Conclusions and future work

The initiative of developing an aircraft sizing tool called FAST has enabled ONERA and ISAE-SUPAERO to investigate several architectures and configurations of aircraft. This code was validated for commercial aircraft applications. A second initiative was to build an open source framework FAST-OAD with the main objectives to provide more modularity and MDAO capabilities.

FAST-OAD uses lightweight models and an efficient MDAO environment which enables to achieve rapid sizings ( $\approx$  seconds) and optimizations ( $\approx$  minutes) for the proposed short medium range commercial aircraft study case. It was also developed to have better modularity to integrate new components/disciplines and/or higher fidelity. The framework provides different usages for different kind of users such as Command Line Interface, Python API, or Jupyter Notebook and Widgets. It has been chosen as the OAD tool for new electric aircraft projects (regional and general aviation). The framework is now online as a beta version.

Future work includes the development of new disciplines such as Direct Operating Costs, electric propulsion, Life Cycle Analysis. Also, new features for the user interface will continue to be further developed such as an data file comparator and 3D geometry rendering. In addition, the integration of higher fidelity for some modules is under study. Furthermore, a broader set of reference use cases such as general aviation or long range are planned to be addressed.

Therefore, FAST-OAD is a new open source framework for sharing, collaborating and synergizing within the OAD community to undertake the challenge of a greener aviation.

## Acknowledgements

The authors would like to acknowledge the community of FAST and FAST-OAD users and developers, the CEDAR and ISAAR research chairs and the Clean Sky 2 JU for contributing to the funding of the framework development.

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