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Leveraging on OpenMDAO to enhance MDO capability @ONERA

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Outline

- Context : MDO at ONERA
- OpenMDAO for overall design : example of FAST-OAD
- OpenMDAO for advanced methods development and teaching
- Generating OpenMDAO code from a web application : WhatsOpt
- Feedback and future needs



Context Why do we use MDO ?

 Pioneering the future of air and space transport, incorporating the related technologies, developing the supporting design tools





Context How do we do MDO ?

• Development of various fidelity parametric models for the relevant disciplines, coupling into an MDAO process, development of numerical exploration methods



Level of fidelity



Context

What about the framework ?

- Early ages (before 2015)
 - Assessment of various off-the shelf or internally developed solutions : Phoenix Integration's ModelCenter, DAKOTA toolsuite, Matlab scripts, Excel-based MDA,...
 - Identification of the main needs : open-source, standardized, flexible framework, to be shared with many partners, with possible custom adaptations
 - Final choice not to develop an internal solution



- From 2015 : side developments around OpenMDAO to meet our specific needs
 - Need for application-specific MDO processes -> example of FAST-OAD (part I)
 - Need for shared use-cases for publication and teaching -> some examples (part II)
 - Need to help the architect through code generation -> WhatsOpt application (part III)





Part I – The FAST-OAD aircraft design code



FAST-OAD: an OpenMDAO based aircraft sizing tool Needs for conceptual design

• Assembly of disciplinary modules in a consistent, parametric process able to size a given aircraft upon Top Level Requirements (Range, PAX number, span,...)





FAST-OAD: an OpenMDAO based aircraft sizing tool Code overview





* Christophe David, Scott Delbecq, Sébastien Defoort, Peter Schmollgruber, Emmanuel Benard, Valérie Pommier-Budinger, From FAST to FAST-OAD: An open source framework for rapid Overall Aircraft Design, 2021 IOP Conf. Ser.: Mater. Sci. Eng.1024 012062.

https://github.com/fast-aircraft-design/FAST-OAD

FastOAD* conceptual design framework:

- OpenSource framework developed by ONERA/ISAE-Supaero
- Based on OpenMDAO
- Automates MDA/MDO for simple and rapid OAD studies, concept evaluation and optimization
- Includes Level 0 disciplinary models for transport aircraft (geometry, weight, HQ, aerodynamics, mission/performance...)
- Modularity of each discipline model to include higher fidelity modelling



FAST-OAD: an OpenMDAO based aircraft sizing tool More insight in the implementation



 Each FAST-OAD model is a standard OpenMDAO component, simply associated to a FAST-OAD identifier



 Currently two open-source libraries of models are available, one for CS-25 A320 like aircraft (<u>https://github.com/fast-aircraft-design/FAST-OAD_CS25</u>), one for CS-23 general aviation (<u>https://github.com/supaero-aircraft-design/FAST-GA</u>)



FAST-OAD: an OpenMDAO based aircraft sizing tool More insight in the implementation



- Models are assembled through a configuration file to define the MDA
- Modules can be custom, or coming from available distributions through pip install
- Modules (or submodules) are called through their unique identifier
- OpenMDAO problem is automatically generated connecting variables with the same name, and I/O files are generated

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FAST-OAD: an OpenMDAO based aircraft sizing tool More insight in the implementation







FAST-OAD: an OpenMDAO based aircraft sizing tool Some achievements

 FAST-OAD used as a base tool for application-driven method developments and assessment of promising novel concepts







Part II – Some other applications using OpenMDAO



Additional studies using OpenMDAO capabilities Open MDAO applied to UAV design

- PhD work of Luiz F. Tiberio Fernandez (ONERA-ENAC)
 - A tail-sitter vehicle was designed for 13th edition of the International Micro Air Vehicle Conference and Competition.
 - The MDO process originally consisted in 3 disciplines: *aerodynamics* (OpenAeroStruct), *weights* and *performance*. After wind tunnel and flight test campaigns, the modules were refined and a *propulsion* analysis (CCBlade) was added to account for available thrust.
 - As future work, trajectory optimization and control feasibility will be addressed within the optimization loop, using DYMOS







Additional studies using OpenMDAO capabilities OpenMDAO / DYMOS for global sensitivity analysis ?

- Goal : use DYMOS for UQ for launch vehicle in an framework coupling All-At-Once (AAO) formulation and pseudo-spectral optimal control
- Sensitivity Analysis : DGSM Derivative-based Global Sensitivity Measures $(2) - (df)^2$

$$v_i^{(2)} = \int_{\mathbb{R}^d} \left(\frac{\mathrm{d}f}{\mathrm{d}u_i}(\mathbf{u}) \right)^2 \phi(\mathbf{u}) \mathrm{d}\mathbf{u}$$

- Need to compute derivative of optimal objective function with respect to uncertainties (and not design variables)
 → use of post-optimality analysis
 - Sampling of uncertainties according to $u \sim \Phi_U(\cdot)$
 - For each realisation of uncertainties → AAO coupled with DYMOS optimization
 - Post-treatment of optimal results to provide the derivative of objective and constraint functions with respect to uncertainties (frozen parameters during the optimization, that are not considered as constant for the global sensitivity analysis)
 → post optimality analysis by gathering Lagrange multipliers from Scipy optimizer
 - For this study, need to harcode Scipy wrapping fortran methods (slsqp) that are quite complex to maintain





Additional studies using OpenMDAO capabilities Teaching activities

- MDO course at ISAE-Supaero and student projects using OpenAeroStruct
 - Nathalie Bartoli, Thierry Lefebvre, Sylvain Dubreuil



 MDO course at Ecole Polytechnique and student projects using FELIN (an OpenMDAO based launcher design process)



Part III – New developments in the WhatsOpt web application



WhatsOpt web application Overview

- Web application for MDO
 - MDA edition
 - Code generation:
 - Execution framework (<u>OpenMDAO</u>, <u>GEMSEO</u>)
 - DOE, Surrogate models (<u>SMT</u>)
 - Sensitivity Analysis (SALib)
 - Uncertainty studies (<u>OpenTURNS</u>)
 - Distributed execution
 - Parallel execution (DOE with Linux MPI)
 - Result Data import / export
 - Result Data visualisation

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Functions	g2	Neg Constr	aint Float	1						
Functions	f	Min Object	ive Float	1						
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Open Source : <u>https://github.com/OneraHub/WhatsOpt</u> Article et Documentation : <u>https://github.com/OneraHub/WhatsOpt-Doc</u> Videos Youtube : <u>Tutorial</u> External server: <u>https://ether.onera.fr/whatsopt</u> Contact : remi.lafage@onera.fr



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WhatsOpt web application Overview





RÉPUBLIQUE FRANÇAISE Henry Junit Manition The FRENCH AEROSPACE LAB

WhatsOpt web application Some recent developments

• For an interactive demo, have a look at the most recent videos





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ONERA WhatsOpt 🛞



- Introduction to EGMDO formulation (Efficient Global MDO)
 - Replacing disciplinary solvers by surrogate models



How to control the accuracy of the surrogate-based MDA?



- Introduction to EGMDO formulation (Efficient Global MDO)
 - Using the properties of gaussian processes to sample the MDA and add points to the surrogate models to converge efficiently the MDA
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- Introduction to EGMDO formulation (Efficient Global MDO)
 - Assessment on an aero-structural problem

Gaspard Berthelin, Sylvain Dubreuil, Michel Salaün, Nathalie Bartoli, and Christian Gogu. Disciplinary proper orthogonal decomposition and interpolation for the resolution of parameterized multidisciplinary analysis. International Journal for Numerical Methods in Engineering, 123(15):3594–3626, 2022.

- Static aero elastic problem (coupling between FEM solver and VLM solver)
- 8 parameters (angle of attack, speed, skin, ribs and spars thicknesses)
- Multi-query context: we want to solve the MDA on a random DoE of size 100

	Structure solver calls			solver calls	
Method	Offline	Online	Offline	Online	Total
Exact MDA	0	392	0	392	784
DPOD+I	50	78	60	6	194



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0.5 1 1.5 2 2.5 3 3.5 4 4.5





- Implementation using WhatsOpt and OpenMDAO
 - From a classical XDSM-described problem, construct surrogate models, performs random MDA computation and iteratively solves the MDA



Feedback and future needs

Wrap-up

- OpenMDAO has become a daily tool at ONERA
 - Hidden behind mostly all our conceptual design processes
 - Used as reference for setting up documented test cases for methodology development
 - Shared for teaching purposes
- Some capabilities built upon OpenMDAO
 - FAST-OAD and WhatsOpt available open source to the community
 - We are happy to get feedback on the potential use of these by the community
- Future steps : OpenMDAO is still underexploited
 - More extensive implementation of derivatives in all components
 - Use toward high-fidelity codes incorporation and hi-fi optimization
 - Deployment of UQ approaches within our processes



Feedback and future needs

Our roadmap and expectations

- Maintain and further develop our processes
 - Backward compatibility of OpenMDAO
 - Support from the development team
- Strong investment in UQ in a design context
 - Definition of probabilistic variables in OpenMDAO ?
 - Post-optimal analysis as a new functionality for OpenMDAO and DYMOS ?





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Thanks for your attention. Any question?



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