Airframe - On Board System - Propulsion System Optimization for Civil Transport Aircraft: AGILE EU project

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ABSTRACT

As part of H2020 EU project "AGILE", a Collaborative System of Systems Multidisciplinary Design Optimization research approach is presented in this paper. An approach to integrate airframe design analysis, as well as propulsion system, aircraft on-board systems, aerodynamics, structures and emission analysis in the early design process is presented. Moreover, the aim of this approach is to exploit the coupling parameters in an integrated analysis and optimization approach. Further, the disciplinary analysis modules from multiple organizations involved in the optimization are integrated within a distributed framework. The disciplinary analysis tools are not shared, but only the data is shared between partners through a secured network of framework. The collaborative design process is implemented by making use of XML based standard Common Parametric Aircraft Configuration Scheme (CPACS), which is the basis for communication within distributed framework to exchange model information between the multi-disciplinary analysis modules and between partner organizations involved in the research activity. The framework is validated with a regional jet passenger reference aircraft. The Sensitivity of varying Engine By Pass Ratio, On-Board System Architectures (Conventional/More Electric/All Electric) is performed through disciplinary modules, effects propagated and its impact on overall aircraft performance in terms of Fuel Burn, Emission and Life Cycle Cost is presented.

KEYWORDS: *Aircraft Design, Multi-Disciplinary, AGILE, CPACS, Optimization*

1 INTRODUCTION

1.1 Need for Collaborative MDO

As the complexity of aircraft design increases, several disciplinary analyses need to be performed. Generally, as the fidelity of the disciplinary analysis increases, the disciplinary expertise does not exist within a single group, and the analysis codes and expertise are spread across several organizations. To solve the challenging complexity of MDO, the distributed competence across organizations needs to be brought together within a collaborative framework, with a standard approach and interface for communication between the disciplinary modules. This requires new MDO methodologies. Thus, to enable the third generation of MDO, whose challenges are presented in [1], the AGILE Consortium has formulated a novel design methodology, collaborative, large scale design and optimization frameworks, and that in particular (as shown in Figure 1) will:

- Accelerate the setup and the deployment of distributed, cross-organizational MDO processes
- Support the collaborative operation of design systems: integrate specialists and tools
- Exploit the potentials offered by the latest technologies in collaborative design and optimization

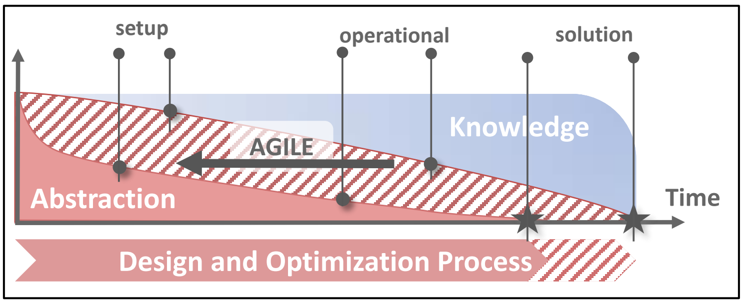

Figure 1: MDO Paradigm Shift

1.2 Collaborative MDO framework: AGILE Project and the AGILE Paradigm

AGILE Project is an EU initiative to research on Collaborative MDO processes that target significant reductions in aircraft development costs and time to market, leading to cost-effective and greener aircraft solutions. To cope with the challenges of collaborative product development, a team of 19 industry, research and academia partners from Europe, Canada and Russia have joined their efforts.
The overall methodology is introduced in [2]. The implementation of the AGILE Paradigm enables effective collaborative design and optimization of aircraft practiced by heterogeneous design teams, located multi-site, and with distributed expertise. The main elements composing the AGILE Paradigm are the Knowledge Architecture (KA), and the Collaborative Architecture (CA). The first formalizes the overall product development process as a hierarchical layered-structured process. The latter formalizes the collaborative development process, and defines how the multiple stakeholders, acting within each layer of the development process, interface with each other within the entire supply chain. The Collaborative Architecture enables cross-organizational and cross-the-nation integration of distributed design competences of all project partners. The overall AGILE Paradigm is implemented in the so-called AGILE Development Framework (ADF), which defines the overall MDO platform developed in AGILE. The Collaborative Architecture defines the required collaboration elements which need to be deployed to enable effective collaboration within the ADF. The ADF is used for the Collaborative Development Process of aircraft or other complex systems, and can be used to support multiple development stages, such as feasibility studies, conceptual design and/or detailed design. An extensive description on AGILE development process is given in the companion paper I. Gent et al [3], with focus on the AGILE Knowledge Architecture. The Collaborative Architecture aspect is presented in detail in Ciampa et al [4].The focus of this paper is on the application of using the AGILE Paradigm, Knowledge and Collaborative Architecture to solve system of systems MDO on a regional jet transport aircraft.

2 INTEGRATED MDO FRAMEWORK

AGILE project is focused on the details of the integration and optimization of the following main disciplinary analysis tools: airframe design, engine, aircraft systems, aerodynamics, structures, nacelle, engine airframe integration, costs and emissions. The MDO system of systems framework is set up for the analysis and optimization of these disciplines for a given set of requirements.
For a given airframe and mission requirements, several engines with parameters such as Bypass Ratio (BPR), Max Cruise Thrust, Bleed extraction strategies are evaluated in the framework. This engine – airframe optimization is carried out for 4 aircraft system architectures with varying degree of electrification (each system architecture has different Offtake implications on engine and hence fuel consumption). Further is designed based on engine parameters nacelle design and high fidelity engine airframe aerodynamic integration optimization is performed. With aerodynamics, structural

weight, engine performance, system weight and integrated nacelle drag, mission simulation evaluates the fuel consumption. Emission and cost estimations are carried out for each combination of above mentioned architectures.

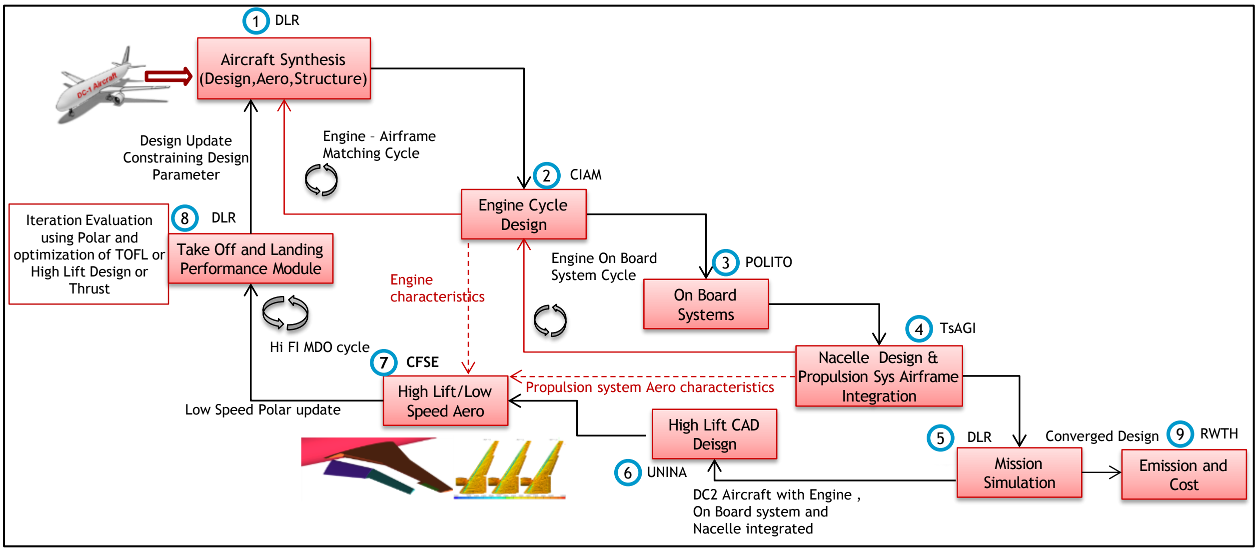

Figure 2: AGILE DC2 Hi Fi Multi-Disciplinary Optimization Integration Flowchart

As shown in the Figure 2, the Initial Aircraft as per TLAR from DC-1 (Design Campaign -1) is used for Hi Fi MDO optimization.

The MDO integration flowchart is as follows:

1. DLR : Initial synthesis based on requirements and Medium Fidelity Aero-Structure analysis is performed
2. CIAM: Based on Thrust requirement Engine is designed through an iterative Engine-Airframe design matching cycle
3. POLITO: On Board System (OBS) is designed based on the TLAR, aircraft geometries and masses and OBS architectural requirements (More electric or all electric or conventional). Weight and power offtakes are evaluated. Further OBS effect on Engine offtakes are considered in Engine-On-board system cycle.
4. TsAGI: The Engine parameters are considered for nacelle design and integrated on the airframe. The propulsion system integration and aerodynamic optimization is performed at this point.
5. DLR: Mission simulation is performed with updated Weights, Aerodynamics and Engine performance, Fuel estimations are made. But these are hi fi cruise aerodynamic optimization. Hi fi low speed aero was desired for evaluating correct thrust and take off performance.
6. UNINA: High Lift Design and CAD geometry generation was made to feed to Hi Fi low speed aerodynamics evaluation
7. CFSE and UNINA: Low speed aero performance was evaluated and polars updated for further iteration.
8. DLR: Take Off and Landing Analysis will be performed with updated Drag polar for low speed regime and design optimization iteration with respect to High lift device, Engine Thrust(installed), Take off field length will be made. A trade-off analysis.
   1 DLR: Again the second iteration for design optimization is started
9. RWTH: The converged design is evaluated for emission characteristics and life cycle cost. At this point of the project the fuel efficiency is the primary objective function, hence the cost and emission is not inside optimization loop.

Note : The focus of the paper is Integration and results of propagated effects upto 5. The results obtained from Step 6,7 (CEAS 2017 Paper ID 254 and 272) will be used in step 8,9 for optimization. Which will be updated and presented at the conference.

3 DISCIPLINARY MODULES

3.1 Airframe synthesis including structure and aerodynamics

The Airframe Synthesis Module consists of a multi-disciplinary, multi-fidelity overall aircraft design system under development at DLR, Germany. The design system is deployed as a decentralized design process, comprising multiple disciplinary analysis and design modules suitable for the pre-design stages. DLR's VAMPzero is an object oriented tool for the conceptual synthesis of aircraft. VAMPzero uses empirical and publicly available aircraft design data and the classical methods available in aircraft design or developed in-house.
Aerodynamics: For the current study, a Vortex Lattice Method (VLM) aerodynamics module from DLR, based on the well-known AVL solver, is chosen to calculate the aerodynamics characteristics.
Structures: An aero-elastic structural module from DLR is used for the loads calculation and a FEM based structural sizing of the main structural components. The detailed description or Aero-structural aircraft design can be found in paper by Zill et al. [5] and Ciampa et al.[6]
Link to other disciplinary modules/tools: The Aerodynamics Module provides drag polars for structure load analysis as well as to Mission Performance Simulation-to calculate fuel consumption. Structures Module provides airframe wing, fuselage and empennage weights for Aircraft Systems Module and Mission Performance Simulation Module

3.2 Propulsion Systems

Commercial software tools level 1 (L1) for engine modelling were used. Level 1 whole engine simulation tool corresponds engine simulation using 0-level simulation of engine components (compressors, turbines, combustor, etc.), i.e. "black boxes" without detailed (1D-3D) modelling.
Engine analysis module evaluation is based on the operational assumptions, Entry into Service time, engine configuration, power offtake/overboard bleed. The module provides engine installation losses, engine flight envelope, intake pressure recovery description, thrust specifications and engine sizing, thrust reverser ability, engine technical deliveries, engine performance for different operating conditions, engine dimensions description, engine sizing rules, automatic handling of air bleed.
A steady state engine performance is represented by an Engine Deck (ED). The engine deck provides the engine performance for the engine operating envelope (Figure 3). ED for unmixed Geared TurboFan (GTF) with high BPR were provided to AGILE partners.

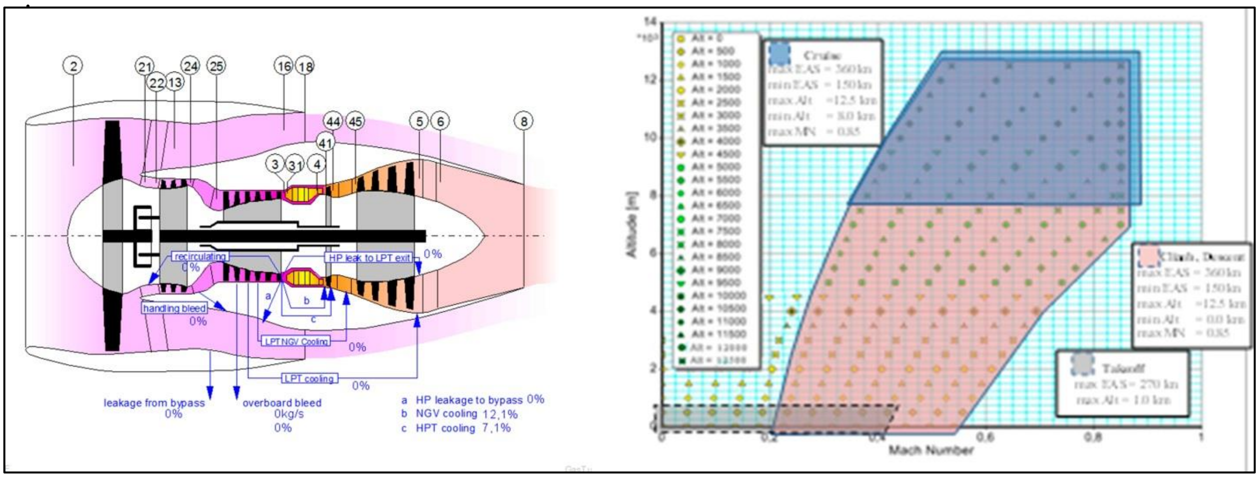

Figure 3: Engine Stations and flight envelope for different flight segments

Link to other disciplinary modules/tools: The Propulsion System Module provides engine performance map/deck to Mission Simulation Module, provides engine geometric parameters to Nacelles Design Module and extracts offtake assumptions from Aircraft System Module.

3.3 Aircraft Systems (Degree of electrification)

For aircraft system analysis, ASTRID - Aircraft on-board Systems sizing and TRade-off analysis in Initial Design, a tool from Politecnico di Torino [7] is used. ASTRID designs power consuming and power generation on-board systems. The first encompass the avionics, the Flight Control System (FCS), the landing gear, the Wing Ice Protection System (WIPS), the Cowl Ice Protection System (CIPS), the Environmental Control System (ECS), the Auxiliary Power Unit (APU) system, the furnishing and the fuel system. In the latter category, the Electric Power Generation and Distribution System (EPGDS), the Hydraulic Power Generation and Distribution System (HPGDS) and the Pneumatic Power Generation and Distribution System (PPGDS) are considered. The system synthesis tool evaluates the given system architectures and provides power offtakes and bleed air requirement together with weight estimation. The power requirement is used by engine module to provide fuel flow for each point in flight envelope for respective bleed and shaft power offtakes. Moreover, the engine module recalculates the engine specific fuel consumption accordingly with the amount of power offtakes and bleed air required [8].

For current study, four system architectures are evaluated. These four architectures are based on different "Degree of Electrification".

i) **Conventional Architecture CONV:** All actuators use hydraulic technology, the WIPS and the ECS are supplied by high pressure air bleeded from the engine and the electric system generates 115 VAC 400 Hz by Integrated Drive Generators (IDGs), then electric power is converted to 28 VDC (Figure 4 i).

ii) **More Electric Architecture MEA 1:** It derives from the Conventional Architecture, but all actuators are electric, and the electric system generates 235 V AC wild frequency (wf) by alternator. Then electric power is converted to 270 VDC, 115 VAC and 28 VDC (Figure 4 ii).

iii) **More Electric Architecture (Bleedless configuration) MEA 2:** The peculiarity of this architecture is represented by the electrification of the WIPS and the ECS. The wing is indeed protected by heat generated by electrical resistances. The electric system generates 235 V AC wf by alternator and then electric power is converted to 270 VDC, 115 VAC and 28 VDC (Figure 4 iii).

iv) **All Electric Architecture (Bleedless configuration) AEA:** This architecture joints the innovations of MEA 1 and MEA 2. The hydraulic system is removed as all the actuators are moved by high voltage electric power. No bleed air is required, the pneumatic power is produced by dedicated compressors. (Figure 4 iv).

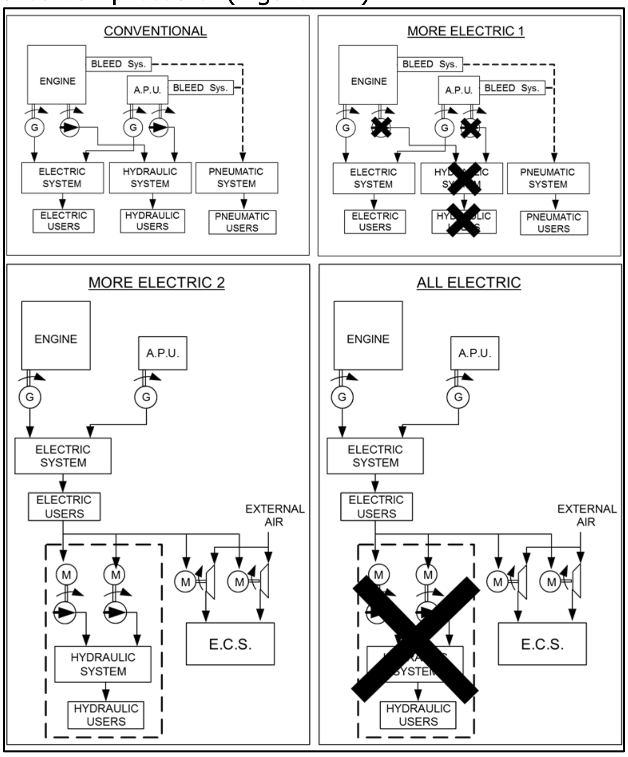

Figure 4: On-board system Architectures: i) Conventional; ii) More Electric Architecture 1 (MEA 1); iii) More Electric Architecture 2 (MEA 2) and iv) All Electric Architecture (AEA)

Link to other disciplinary modules/tools: The System Synthesis Module extracts information of TLARs, Aircraft cabin geometry, aircraft weight parameters and provides systems and landing gear weight and required secondary power for final synthesis and Mission Performance Simulation module

3.4 Nacelle and Airframe Integration

The nacelle design and nacelle airframe integration is divided into two phases. First, Isolated Nacelle Design based on ambient flow, engine geometry and engine gas dynamics properties (Figure 5) and second, engine airframe integration based on the demand of low installation (Figure 6). For CFD calculations for both phases in-house software Electronic Wind Tunnel (EWT) is used[9]. The Isolated Nacelle Design Optimization is based on 18 geometrical variables. The optimization procedure and features of Isolated Nacelle Optimization process is described in Anisimov et al[10].

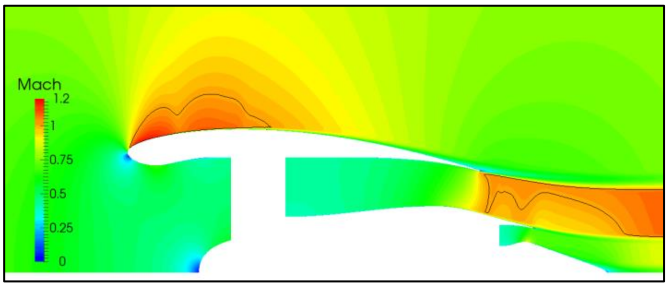

Figure 5: Nacelle Design Optimization. Mach number field at cruise regime

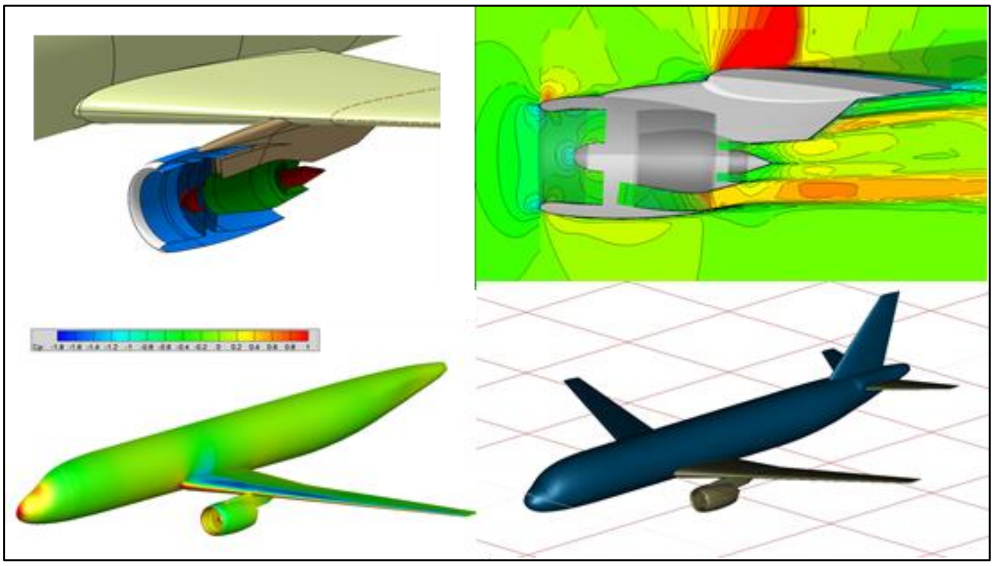

Figure 6: Nacelle Airframe Integration Optimization (TsAGI)

Engine Installation Optimization is based on 5 installation variables. Two installation angles and the three coordinates of the engine displacement have been chosen as independent variable parameters. Engine installation angles: α angle - incidence angle and β - slip angle. The rotation is performed around the lines, which are parallel to Y and Z axes (for α and β, respectively) and pass through the intersection point of the engine axis and the engine entrance plane (the fan plane). The scheme of changes of variable parameters is shown in Figure 7. The optimization technology is the same as for the Isolated Nacelle Optimization.

At each optimization iteration the 3D RANS calculation is done. As a result of solver work, 3D field of the parameters in the cell centers has been obtained. It is necessary to perform the result processing to obtain values of the objective function. As an objective function, the effective losses of engine thrust have been chosen in the current optimization. The effective thrust is calculated as a sum of the aerodynamic loads on hard surfaces plus the difference between the input and output pulses:

$$P_{eff} = (I_x)_{out} - (I_x)_{out} + \sum(F_x)_{wall}$$

The effective thrust losses are calculated through the ideal thrust (that corresponds to the ideal gas expansion process) and the effective thrust using following formula: $dP_{eff} = \left(1-\frac{P_{eff}}{P_{ideal}}\right)\cdot 100\,\%$. This value is minimized during the optimization. Since the ideal thrust P_{ideal} and the input and the output pulses is constant from practical point of view, the engine nacelle drag is minimized.

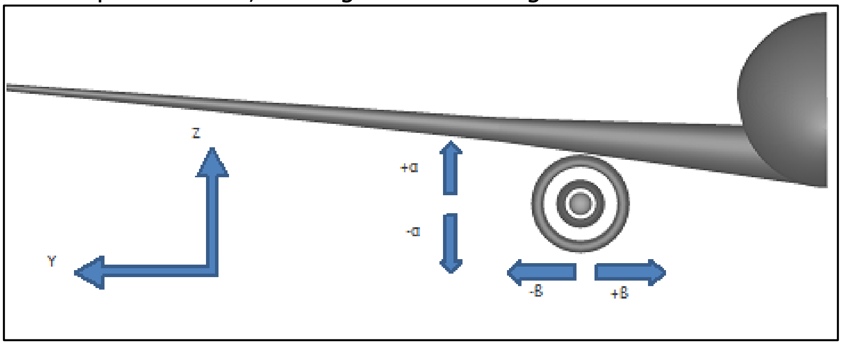

Figure 7: Rotation angles of the engine

For optimal positions of each nacelle the pylons have been designed. During the variation of the nacelle position under the wing, the pylon geometry is changed. In this connection, the input parameters, which are necessary for the designing the pylon geometry, are the geometric model of the wing, engine nacelle and the engine nacelle position under the wing.

Link to other disciplinary modules/tools: Nacelle and Engine Airframe Integration Module extracts information from Aircraft Geometry, Aerodynamics Module, Engine parameters from Engine Module, Offtakes from Aircraft Systems Module and provides optimum Nacelle design to calculate weight and integrated Nacelle Drag. This information is used by Mission Performance Simulation to evaluate fuel consumption for given mission.

3.5 Mission Performance Simulation

The DLR's Mission performance module evaluates the aircraft performance by simulating the given mission phases. The block fuel consumption for given mission and reserve segments are calculated, The FSMS tool uses the drag polars from aerodynamics module, structural weight from structures module, engine deck/engine performance map for analysis. Also the systems weight, Engine weight and Nacelle drag is propagated through Mission simulation to calculate the overall effect of Engine, systems and nacelle on Airframe.

The Typical Mission for AGILE Reference Aircraft is as per Figure 8 below. 3500 km range (Cruise Altitude = 11000m and Cruise Mach = 0.78) in addition reserve mission of 370 Km (Cruise Altitude = 3000m and Cruise Mach = 0.7). The Mission is constant altitude mission and can also be changed to constant CL and many other parametric variations can be made.

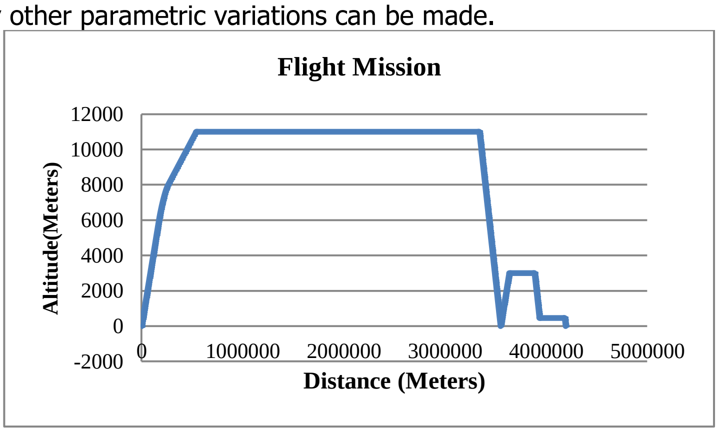

Figure 8: AGILE Reference Aircraft Mission

Link to other disciplinary modules/tools: This tool extracts Aero, Weight and Engine Parameters from all the above modules to calculate Mission Fuel. Also links with Cost and Emission Analysis Module for emission and cost modeling.

3.6 Cost and Emission Analysis

The cost and emission analysis tools of RWTH Aachen University have been developed at the Institute of Aerospace Systems over the last years and can be used for economic and ecological life cycle assessment of commercial transport aircraft. For the purpose of the studies carried out within the scope of this paper, the focus is set on the production and operational phase, since these are considered to reveal the most significant changes with regard to costs and emissions.

Costs: RWTH Aachen's cost module comprises both, non-recurring and recurring costs for an aircraft's life cycle using semi-empirical methods. For non-recurring costs, the methods include for instance costs for development, testing and test facilities, as well as assembly and transport of materials. Operating costs include indirect (administration, staff, etc.) and direct (charges, fees, maintenance, etc.) operational costs of an airline. The concept and sensitivities of the cost analysis tools are described in two research papers by Franz et al.[11] and Lammering et al.[12]

Emission: In the performed analysis, the RWTH Aachen emissions module was used to obtain the emission levels of several emissions with regard to the parameter $DP/F00_{x,i}$. This is the ICAO regulatory parameter for gaseous emissions, expressed as the mass of the pollutant emitted for one incremental step divided by the rated thrust (maximum take-off thrust) of the engine. The total amount of mass for each emission part is then calculated by integration over the whole mission time. For each time step $DP/F00_{x,i}$ is calculated by

$$DP/F_{00_{x,i}} = \frac{EI_i \cdot W_{f,i} \cdot t_i}{F_{00}}, \qquad \text{(eq. 1)}$$

Where $i = 1,\ldots, n$ is the index of the current incremental mission step,
x is the emission part (e.g. CO, CO_2, NO_x, etc.),
$DP/F00_{x,i}$ is the ICAO regulatory parameter for gaseous emissions,
EI_x is the emission index at the current mission step in g per kg of fuel [g/kg],
$W_{f,i}$ is the current fuel flow,
t_i is the time interval of the current mission step,
F_{00} is maximum rated takeoff thrust in kN.

The emission indices EI_x are calculated differently for each emission part. For the analysis carried out in paper it was not possible to obtain all relevant emission parts, due to limitations of the tools used. The emission parts accounted for in this study are NO_x, CO_2, H_2O, SO_2 and soot. The emission index for NO_x was obtained by using the engine performance information at all operating conditions given by CIAM. The indices for CO_2 and H_2O are stoichiometric factors of the combustion and can therefore be considered as constant values. The emission indices for Sulfur Dioxide (SO_2) and soot are also considered to be constant for this study and were obtained from a report of the Intergovernmental Panel on Climate Change (IPCC) from 1999. The information about the amount of emitted pollutants at each incremental flight step and the additional information about the current flight altitude are processed to an implemented climate model, which was introduced by Dallara[13] in 2010. With the help of this model it is possible to account for the actual ecological effects of the pollutant emissions – such as Average Temperature Response (ATR), or Absolute Global Warming Potential (AGWP) – rather than only considering the pure amount of emitted pollutants. The above described methods of the RWTH Aachen emissions module are also further explained in a publication by Franz et al.[14]

Link to other disciplinary modules/tools: Within the scope of the presented SoS MDO use case, the interfaces between the RWTH Aachen modules (MICADO_Costs And Emissions) are twofold. On the one hand, the cost analysis mainly requires information about component sizes, masses, materials, etc. in order to calculate the manufacturing costs. For operational costs characteristic values of interest are e.g. flight duration, frequency, and fuel consumption are additionally required. On the other hand, for the emission assessment, the specified flight mission has to be simulated with focus on exhaust emissions and the respective altitudes at which they are emitted. Therefore, the entire performance mission simulation results at all incremental flight steps are taken as an input for the analysis.

4 REFERENCE CASE

To evaluate the framework, a test case of regional Civil Aircraft is considered (Figure 9). A 2020 Entry into Service specification, conventional single aisle, engine under the wing configuration. The TLAR of the Reference test configuration is provided in Table 1.

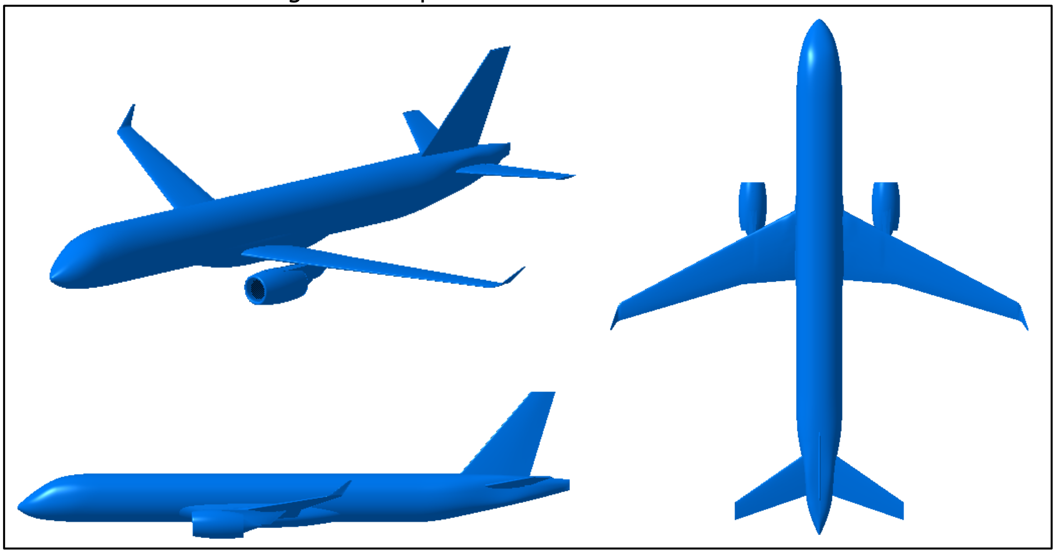

Figure 9: AGILE reference test case configuration for systems of systems MDO

Table 1. TLAR's AGILE Reference Aircraft DC-1

Specification	Metric	Imperial
Range	3500 km	1890 nm
Design payload	9180 kg	20220 lbs
Max. payload	11500 kg	25330 lbs
PAX	90 pax @ 102 kg	90 pax @ 225 lbs
MLW (% MTOW)	90%	
Long Range Cruise Mach (LRC)	0.78	0.78
Initial Climb Altitude (ICA)	11000 m	36000 ft
Maximum Operating Altitude	12500 m	41000 ft
Residual climb rate	91 m/min	300 ft/min
TOFL (ISA, SL, MTOW)	1500 m	4921 ft
Vref (ISA, SL, MLW)	< 130 kts	
Max. operation speed (V_{mo} / M_{mo})	330 KCAS / 0.82	
Dive Mach number (M_d)	0.89	
Fuselage diameter	3 m	118 in
Fuselage length	34 m	111.5 ft
Service life	80,000 cycles	
Fuel reserves	5%	100 nm
A/C configuration	Low-wing, wing-mounted engines	
Engine	Provided (e.g.: PW1700G)	
Design objective	Minimize COC (alternatively, min. MTOW)	

The framework is used to find the sensitivity effects of On-Board Systems, Engines on Airframe.
Assumption: Initial aircraft is given reference aircraft (including reference airframe, engine, OBS, nacelle geometry/position). Engine size is defined during mission performance calculation using engine modeling by takeoff static net thrust FN00

- Basic engine size for all engine decks is engine static thrust FN00 = 78.5 kN
- 4 basic OBS architecture options are considered: 1 conventional, 2 – more electrical and 1 – all electrical architecture

Design Variables: Following 32 parameters were considered as discrete and continuous variable for MDO:

- Airframe - Wing aspect ratio and area (Initially fixed)
- Engine - BPR - 3 Bypass Ratio variables and engine setting combinations
- Aircraft Systems - 4 discrete variables for levels of DE - Degree of Electrification
- Nacelle Design - 18 variables for Nacelle geometry and 5 Nacelle position variables wrt airframe

MDO Global Constraints:

- Range (3500 km)
- Takeoff field length TOFL (1500 m)
- Engine max diameter (installation limitation due to under wing engine location)

5 RESULTS

The Sensitivity results are presented in this section. The detailed disciplinary results can be found in supplementary AIAA Aviation 2017 Paper[15]. This paper has an updated result with correct offtake assumption and framework correction.

5.1 Engine By Pass Ratio effect on Aircraft Performance

The below figures provide the result from DLR's mission simulation post infusion of all the results from different competencies (aero, structure, propulsion systems, nacelle drag) for the given mission requirements. Figure 10 represents the fuel consumption effect due to change in BPR of the engine, Conventional Aircraft system architecture and also the drag of Nacelle and weight of Nacelle considered. The BPR 12 seems to be optimum for the current fixed airframe. **BPR 9 consumes 5.6% more fuel compared to BPR 12 as per the evaluation**. Although BPR 15 is better in terms of SFC, the weight and drag lead to higher fuel consumption. Also the Landing gear weight for BPR 15 would be higher and heavier due to ground clearance issue. The detailed landing gear effect is not presented in the paper.

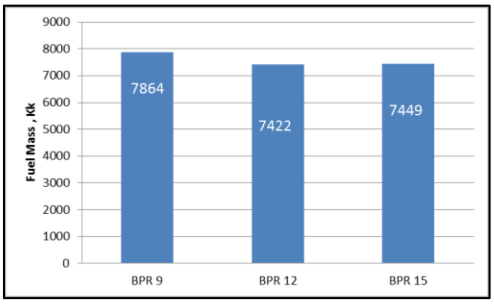

Figure 10: Fuel Mass: BPR 9, 12 and 15 (Conventional Systems Architecture)

5.2 On-Board System Architecture effect on Aircraft Performance

The fuel consumption results of BPR sensitivity in Figure 10 did not assume the correct offtake of Bleed and power extraction for this class of aircraft. After assuming correct offtake conditions the results were changed. The change is highlighted for one Aircraft system architecture in Figure 11. It can be observed that the BPR 12 conventional system architecture with corrected offtake assumption: consumes is 5.6% more fuel than earlier analysis with incorrect offtake bleed assumption.

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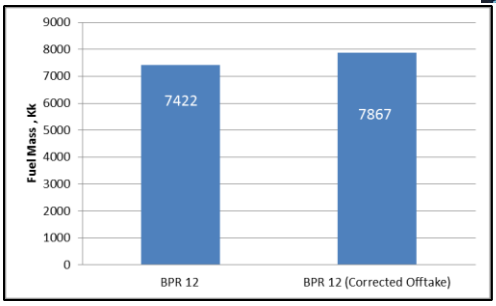

Figure 11 : Fuel Mass for BPR 12 vs BPR 12 corrected offtake (Conventional Systems Architecture)

This evaluation showed that detailed offtake bleed considerations is necessary for Aircraft Design Process, and this study will be repeated for other system architecture which involves bleed. i.e BPR 12 for MEA 1 architecture. Thus, it can be compared with all architectures; Conventional, MEA1, MEA2 and AEA for BPR 12.This method is employed for MDO from hence fourth. Also the devil is in details seems true by this analysis.The Overall comparison of On-Board system effects on Aircraft performance (also considering weight and drag effects) in terms of percentage reduction is presented in Figure 12 and in terms of absolute numbers is presented in Figure 13

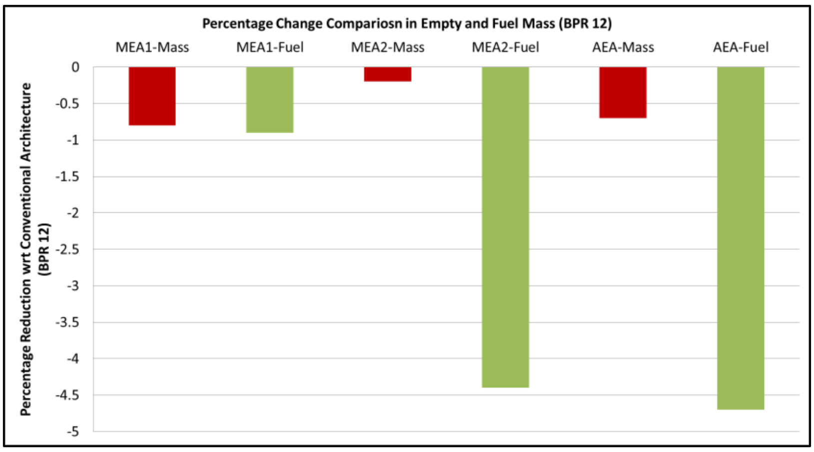

Figure 12: Percentage Reduction of Empty Mass and Fuel with respect to Conventional On Board System Architecture (BPR 12)

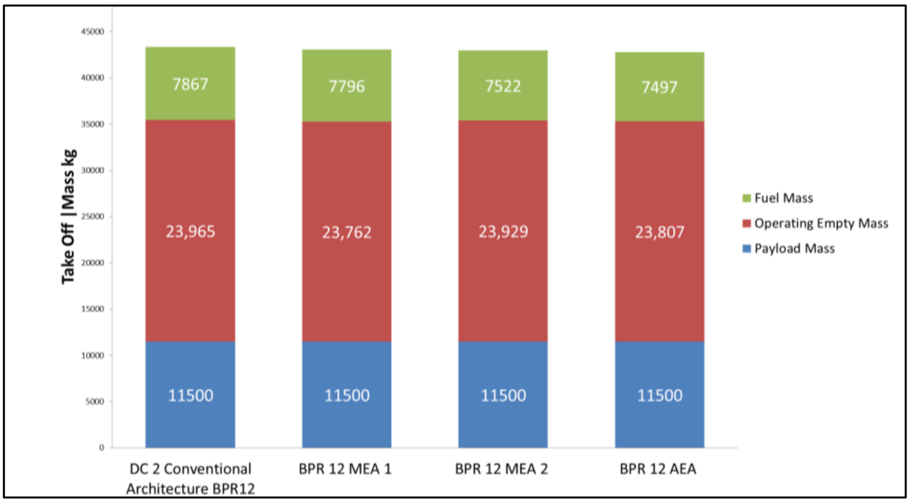

Figure 13: On-Board System effect on Aircraft Performance

Also, the On-Board System comparison results partially validate the correctness of the workflow and disciplinary module (variable coupling) integration since the difference among the On-Board System architectures are large in absolute terms (e.g. 400kg of fuel difference between the conventional and the All Electric architectures) even if very slight compared to aircraft weight (about 1%). It can be notice from the histograms in Figure 13 that bleedless configurations – i.e. MEA2 and AEA architectures – entail lower fuel consumption. The fuel savings of these architectures compared to the conventional one is nearby 4.5%. This result is in line with the outcomes of several other studies and reports regarding the electrification of the on-board systems, as [16],[17] and [18]. However, it is worth noting that the here proposed design problem is a Multi Disciplinary Analysis. Therefore, without converging design and analysis iteration loops, the snow-ball effect and other couplings couldn't be shown. Also it should be noted that, During iteration, Engine can be re synthesised to operate more efficiently according to thrust required at multiple points.

Other observations which validates the framework:

- The fuel required decrease with On-Board System electrification degree
- The MEA1 leads to the minimum OEM (but requires more fuel than the bleedless architectures)
- The MEA2 is one of the lightest options. This architecture can be considered SOTA, as is inspired to the Boeing 787 kind of configuration.
- The AEA is the lightest option, but only considering weights and no other parameters, as costs, reliability and safety. It adopts technologies that should be fully developed.

5.3 On Board System effect on aircraft emission performance

On closer inspection of the four on-board system architectures on the BPR12 engine it becomes clear from Figure 14 that, as expected, the change in exhaust of CO_2, H_2O, SO_2 and soot scales linearly with the amount of consumed fuel (as shown as percentage reduction in Figure 12). Note that the conventional architecture (BPR12_conv) was taken as baseline.

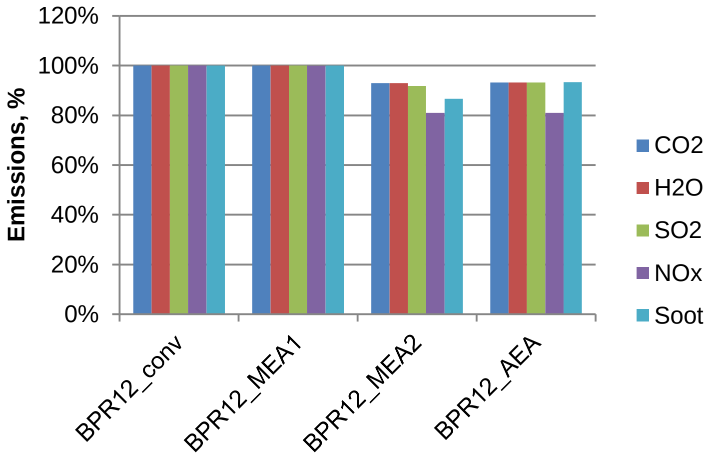

Figure 14: On-board system architecture effect on overall aircraft emission.

6 CONCLUSION

The AGILE MDO framework has been created to consider Airframe, Propulsion Systems, On-Board system and Nacelle Integration. The results shows expected trend. Thus the inter organizational/Distributed Higher Fidelity MDA framework is robust for MDO studies, results of MDO and cost analysis will be updated during CEAS 2017 conference.

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8 REFERENCES

[1] P. D. Ciampa and B. Nagel, "Towards the 3rd generation MDO collaboration Environment," in 30th Congress of the International Council of the Aeronautical Sciences, Daejeon, 2016.
[2] AGILE Paradigm: developing the next generation collaborative MDO," in 18th AIAA\ISSMO Multidisciplinary Analysis and Optimization Conference, Denver, 2017
[3] I. van Gent, P. D. Ciampa, B. Aigner, J. Jepsen, G. La Rocca and J. Schut, "Knowledge Architecture supporting collaborative MDO in the AGILE paradigm," Conference, 2017.in 18th AIAA\ISSMO Multidisciplinary Analysis and Optimization
[4] Ciampa, P. D., Baalbergen, E. H., and Lombardi, R., “A Collaborative Architecture supporting AGILE Design of Complex Aeronautics Products,” 18th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, 2017.
[5] Zill, Thomas, Pier Davide Ciampa, and Björn Nagel. "Multidisciplinary design optimization in a collaborative distributed aircraft design system." 50th AIAA Aerospace Sciences Meeting. 2012
[6] Pier Davide Ciampa, T. Zill, and Bjoern Nagel. "Aeroelastic Design and Optimization of Unconventional Aircraft Configurations in a Distributed Design Environment", 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference Co-located Conferences,2012
[7] Chiesa, Sergio, Giovanni Antonio Di Meo, Marco Fioriti, Giovanni Medici, and Nicole Viola. " Aircraft on board systems sizing and trade-off analysis in initial design." (2012): 1-28.
[8] Fioriti, M., Boggero, L., Corpino, S., Isyanov, A., Mirzoyan, A., Lombardi, R., D’Ippolito, R., “Automated Selection of the Optimal On-board Systems Architecture within MDO Collaborative Environment”, AIAA Aviation 2017, 5-9 June, Denver, USA
[9] Neyland, V. Ya., Bosnyakov, S. M., Glazkov, S. A., Ivanov, A. I., Matyash, S. V., Mikhailov, S. V., and Vlasenko, V. V., “Conception of electronic wind tunnel and first results of its implementation,” Progress in Aerospace Sciences, Vol. 37, No. 2, 2001, pp. 121-145.
[10] Anisimov, K. S. and Savelyev, A. A., “Aerodynamic Optimization of Airplane Propulsion System within the Framework of AGILE Project,” 30 th ICAS Congress, Daejeon, Korea, September 2016.
[11] Franz, K., Lammering, T., Risse, K., Anton, E., and Hoernschemeyer, R., “Economics of Laminar Aircraft Considering Off-Design Performance,” 53rd AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference & 20th AIAA/ASME/AHS Adaptive Structures Conference, American Institute of Aeronautics and Astronautics, Reston, Virigina, 2012.
[12] Lammering, T., Franz, K., Risse, K., Hoernschemeyer, R., and Stumpf, E., “Aircraft Cost Model for Preliminary Design Synthesis,” 50th AIAA Aerospace Sciences Meeting including the New Horizons Forum and Aerospace Exposition, American Institute of Aeronautics and Astronautics, Reston, Virigina, 2012.
[13] Dallara, E. S., Kroo, I. M., and Waitz, I. A., “Metric for Comparing Lifetime average Climate Impact of Aircraft,” AIAA Journal, Vol. 49, No. 8, 2011, pp. 1600–1613
[14] Franz, K., Risse, K., and Stumpf, E., “Framework for Sustainability-Driven Aircraft Design,” 2013 Aviation Technology, Integration, and Operations Conference, American Institute of Aeronautics and Astronautics, Reston, Virginia, 2013.
[15] Prajwal S. Prakasha, Luca Boggero, Marco Fioriti, Benedikt Aigner, Pier Davide Ciampa, Kirill Anisimov, Andrey Savelyev, Artur Mirzoyan, and Alik Isianov. "Collaborative System of Systems Multidisciplinary Design Optimization for Civil Aircraft:AGILE EU project", 18th AIAA/ISSMO Multidisciplinary Analysis and Optimization Conference, AIAA AVIATION Forum, (AIAA 2017-4142)
[16] Cronin, M. J. (1983). All-Electric vs Conventional Aircraft: The Production/Operational Aspects. AIAA Journal of Aircraft, 20(6), 481-486
[17] Rosero, J. A., Ortega, J. A., & Aldabas, E. (2007). Moving towards a more electric aircraft. IEEE Aerospace and Electronic Systems Magazine, 22(3), 3-9.
[18] Tagge, G. E., Irish, L. A., & Bailey, A. R. (1985). Systems Study for an Integrated Digital/Electric Aircraft (IDEA). Hampton (VA): NASA Contractor Report 3840.