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Certification driven design from stakeholders' needs to MDAO formulation within AGILE 4.0 project

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Abstract

Whitin the Horizon 2020 Agile 4.0 research program several studies are performed to integrate certification disciplines in a Multidisciplinary Design Analysis and Optimization environment. Inside this framework, some tools have been developed to formalize and help the integration. The present paper describes the integration of external noise, minimum performance, and safety verification within a multidisciplinary design of a small regional aircraft with electrified on-board systems. The integration is carried out using the Operational Collaborative Environment developed within the project and able to exploit the MBSE technology. Starting from the definition of a possible architecture of the virtual certification process for noise, performance and safety, the necessary disciplinary tools are identified together with possible multidisciplinary design problems. The results are then propagated up to the initial requirements as means of future validation.

Keywords: virtual certification, multidisciplinary design analysis, systems electrification, aircraft design

1. Introduction

Since the last decades, the competitiveness of the aircraft product is increasingly coupled with the optimization of the whole aircraft leaving the past practice of optimizing each single discipline (1). In this way, the Multidisciplinary Design Analysis and Optimization (MDAO) represents a best practice needed from the first phase of the aircraft design. However, considering the complexity of the product and the related industries, the MDAO still represents a challenge from a technical and organizational point of view. The MDAO intensifies the interactions between disciplines and disciplinary offices increasing, in turn, the complexity of the design phase. Agile 4.0 is a H2020 research project (2), (3) focused on reducing aircraft development time by means of several tools grouped in the Operational Collaborative Environment (OCE). The OCE is based on Model Based Systems Engineering (MBSE) tools, and it is able to cover the design phase from the Top Level Aircraft Requirements (TLARs) definition to the MDAO formulation. The OCE is accessible by each disciplinary expert who has the opportunity to give his/her contribution to the definition of the MDAO problem. In particular, the OCE covers the needs of formalization, the TLARs and scenario definition, the systems architecture definition and, finally, the MDAO formulation. The present paper is aimed at describing how the design study is implemented in the OCE and the pros and cons of this approach. In this framework, the development of a MDAO study of a small regional aircraft is implemented as an application case (4), (5). However, other application cases have been developed within the project (6), (7). The main aim of the application case here analyzed is to study the effect of certification constraints on aircraft cost when new technologies are applied (8). The new technologies considered are the electrification of the On-Board Systems (OBS). This technology leads to some More Electric Aircraft (MEA) and All Electric Aircraft (AEA) architectural concepts (9), (10). In general, the electrified small regional aircraft is justified by the following needs:

- The need for a point-to-point connection avoiding the use of congested hub to reduce trip time and cost. The point-to-point connection concept leads to a reduction of aircraft size. The actual small transportation fleet is not designed to be cost efficient and cost effective.
- The need for a reduction of pollutant emissions and cost. MEA and AEA concepts increase the aircraft efficiency reducing their emissions (11), (12), (13).

In the described context, a small propeller driven transportation aircraft, carrying up to 19 passengers is investigated. The certifiability of the aircraft is verified changing the electrification level and applying, separately, part of CS 23 and CS 25 regulations.

The present paper describes the whole process for MDAO formulation following the steps described in Figure 1.

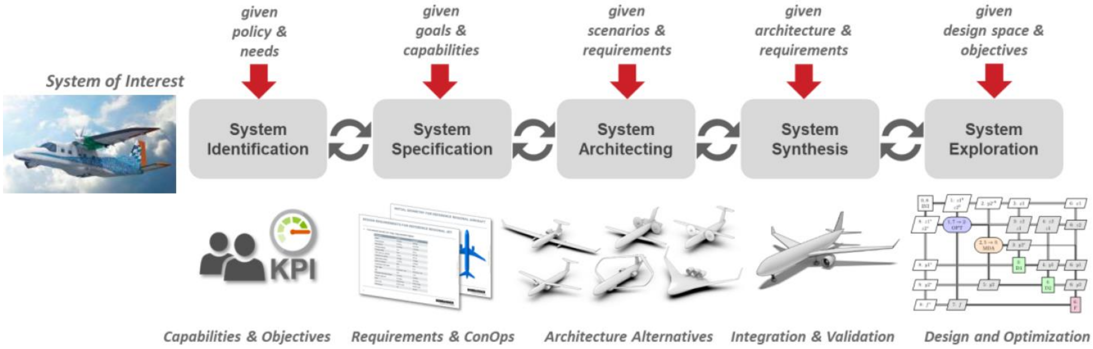


Figure 1 AGILE 4.0 process for MDAO formulation

2. Needs, scenario and TLARs definition

The first step of the application case implementation is the formalization of the stakeholders' needs, scenario and TLARs. To define the needs a list of possible stakeholders is outlined:

- Airliners: they are the final users of the aircraft; their needs should drive directly the aircraft design and the need for electrified systems.
- OEM (Original Equipment Manufacturer): they collect the needs from all the stakeholders to design the aircraft accordingly. The OEM will decide the best electrification level of the aircraft systems.
- Politics/society: They are an indirect stakeholder that could require system electrification considering their environmental effect.
- Passengers: The passengers may have needs that may make one system - with a specific electrification level – preferred over the standard one even they are not aware of the specific technology used.
- Airport authority: This stakeholder has been included since the possible effect on ground services/support equipment given by the use of electrified systems.
- Certification authority: Considering the certification process of an aircraft with innovative systems, this stakeholder may necessitate of additional activities/support.
- Pilot: the needs of the pilot should be taken into account (at least for safety reasons) to be sure that the electrified systems will have similar behavior and/or management of the standard one.

For each stakeholder a list of needs is defined. An excerpt of the complete list is shown in Table 1. For the sake of brevity and considering the purpose of the paper, the most important needs can be summarized as follows:

- Need of a small air transport system to operate from small airport reducing door-to-door time
- Need to reduce the environmental impact of the air transport system
- Need of reducing the aircraft Life Cycle Cost

- Need of reducing the time-to-market and certification effort especially when new technologies are used

Table 1 List of the stakeholders' needs (excerpt)

Stakeholders	Phase	Aspect	Needs
Airliner (ARL)	Acquisition	Benefit (achieve)	entry in service before 2035
	Acquisition	Benefit (achieve)	able to execute desired routes with desired schedule
	Acquisition	Benefit (achieve)	ability to enter controlled airspace
	Acquisition	Cost (control)	low acquisition and preparation cost
	Use	Benefit (achieve)	Transport 19 passengers at a distance of 370 km in 60 minutes
	Use	Benefit (achieve)	low noise emission and pollution (i.e. anticipate taxes increase)
	Use	Benefit (achieve)	access small airports
	Use	Benefit (achieve)	minimal lost in range / passengers (usable load) compared to conventional OBS/prop
	Use	Benefit (achieve)	low turn around time
	Use	Benefit (achieve)	High Availability
	Use	Benefit (achieve)	High dispatch reliability
	Use	Benefit (achieve)	High availability of spare parts
	Use	Cost (control)	min operating costs
	Use	Cost (control)	minimum airport service costs
	Use	Cost (control)	low pilot training cost
	Use	Cost (control)	low maintenance cost (including rate, time)
	Disposal	Benefit (achieve)	max remaining aircraft value
OEM	Development	Benefit (achieve)	reliable systems architecture (similar safety level as conventional)
	Development	Benefit (achieve)	low certification time
	Development	Cost (control)	low certification cost
	Marketing	Benefit (achieve)	competitive product (low price)
	Marketing	Benefit (achieve)	comply with airliners mission requirements
	Marketing	Benefit (achieve)	provide the aircraft according to the entry in service time from airliners
	Production	Cost (control)	low production cost (ex: less number of parts)
	Support	Benefit (achieve)	robust systems
	Support	Benefit (achieve)	Fast and easy maintenance
	Support	Benefit (achieve)	Exclusiveness of spare parts/monopoly
	Support	Cost (control)	low maintenance cost
	Phase out	Benefit (achieve)	good materials recycling capability

Following the MBSE process (14), starting from the needs, it is possible to define the requirements at system and subsystem level. An excerpt of the full list of the requirements at system and subsystem level is shown in Table 2. The needs that generated each requirement is traced as well as the connected requirements at higher and lower level. Therefore, considering the above summarized needs and for the sake of brevity, the main requirements obtained are, respectively:

- 19 passenger aircraft, able to operate from/to a 800m length airport, having a maximum range of 370 km
- The aircraft shall use efficient propulsion system (turboprop engine) and increase the electrification level of its OBS
- The aircraft shall have a low operating cost and acquisition and certification cost
- The aircraft shall be readily certifiable before the certification activities

The last requirement calls for an integration of a virtual certification system from the first design phase. It means that a series of tools should be integrated in the MDAO environment to constantly check the fulfillment of the certification constraints and to compare the certifiability of each design variant during trade-off phase.

Table 2 List of the system requirements (excerpt)

ID	Needs	Requirement statement	Type	Parent/Source	Means of Compliance	Stakeholders
MR1	Transport 19 passengers at a distance of xx km in xx minutes, comply with airliners mission reqs, increase the number of flight connection, reduce door to door time	The standard mission shall be performed in 60 minutes	Performance	1.1, 2.2, 4.4, 5.1	OpenAD	ARL, OEM, SCT, PAX
MR2	Transport 19 passengers at a distance of xx km in xx minutes, comply with airliners mission reqs, increase the number of flight connection, reduce door to door time	The standard mission shall provide for the transport of 19 passengers at a distance of 370 km	Performance	1.1, 2.2, 4.4, 5.1	OpenAD	ARL, OEM, SCT, PAX
MR3	access small airports, increase the number of flight connection, reduce door to door time	The standard mission shall be performed from airports with a minimum runway length of 800m	Performance	1.2, 4.4, 5.1	OpenAD	ARL, SCT, PAX
MR4	low turn around time, High dispatch reliability, High availability, Fast and easy maintenance, High availability of spare parts, Easy accessibility, availability of support equipment and instruments, standardization, Clearly defined maintenance procedure, Not being disturbed by maintenance activities, Departure on time, High dispatch reliability, High dispatch flights/hour, Receive fast and precise failure report in case of malfunction, Walkaround should be carried out fast and easy, Isolation of faulty system should be possible from cockpit, Failure detection should be possible from cockpit (build in test capability for equipment)	The standard mission shall be repeated after 20 minutes	Suitability	1.3, 1.11, 1.12, 1.13, 1.14, 2.10, 3.1, 3.2, 3.4, 3.5, 3.9, 3.10, 5.6, 5.7, 6.3, 6.5, 8.1, 8.2, 8.3, 8.4	TBD	ARL,OEM, MNT, PAX, ARP, PLT

Finally, considering the purpose of the application case, the scenario is represented by the aircraft certification activities. They are here implemented as a series of simulated test campaigns where the designed aircraft is checked considering its:

- Minimum performance during takeoff and landing
- External noise level
- Safety performance of the OBS architecture

3. Architectures definition

Following the MBSE process, before creating the MDAO, the definition of the systems architectures and possible tradeoff analysis is necessary (15). The architecture of several systems have been studied, the one related to the FCS (Flight Control System) and the architecture of the Virtual Certification System (VCS) are here discussed. The architecture modelling of the FCS is shown in Figure 2.

The architecture of the FCS starts from the main function of the system for the AC3 that is "move secondary surface". Staring from the requirements and needs formalized, it is possible to trace the origin of this function up to the stakeholders' needs. Firstly, this function is derived from the following FCS requirement: "The FCS shall permit the control of the aircraft" that in turn is derived from the following aircraft requirement: "The aircraft shall perform the standard mission". Secondly, this last requirement is derived from the following needs:

- Transport 19 passengers at a distance of 1500 km in 90 minutes (Airliner's need)
- Comply with airliners mission requirements (Original Equipment Manufacturer's need)

- Common aircraft control systems and aircraft handling qualities (Pilot's and Certification Authority's need)

In the reference aircraft, the primary control surface is mechanically controlled. Two main functionalities branch off from the main function:

- Move the secondary surface in flight
- Move the secondary surface on ground

In this way, different load cases for the flap are taken into account also identifying the need of creating aerodynamic forces to control the aircraft. Considering this last function and the different loads two main component of the system are identified:

- movable surface
- mechanical actuators

Then a new part of the architecture is dedicated to different technological solutions needed to provide power to the mechanical actuators:

- Gearbox system driven by hydraulic motor
- Gearbox system driven by electric motor
- Direct drive electric motor

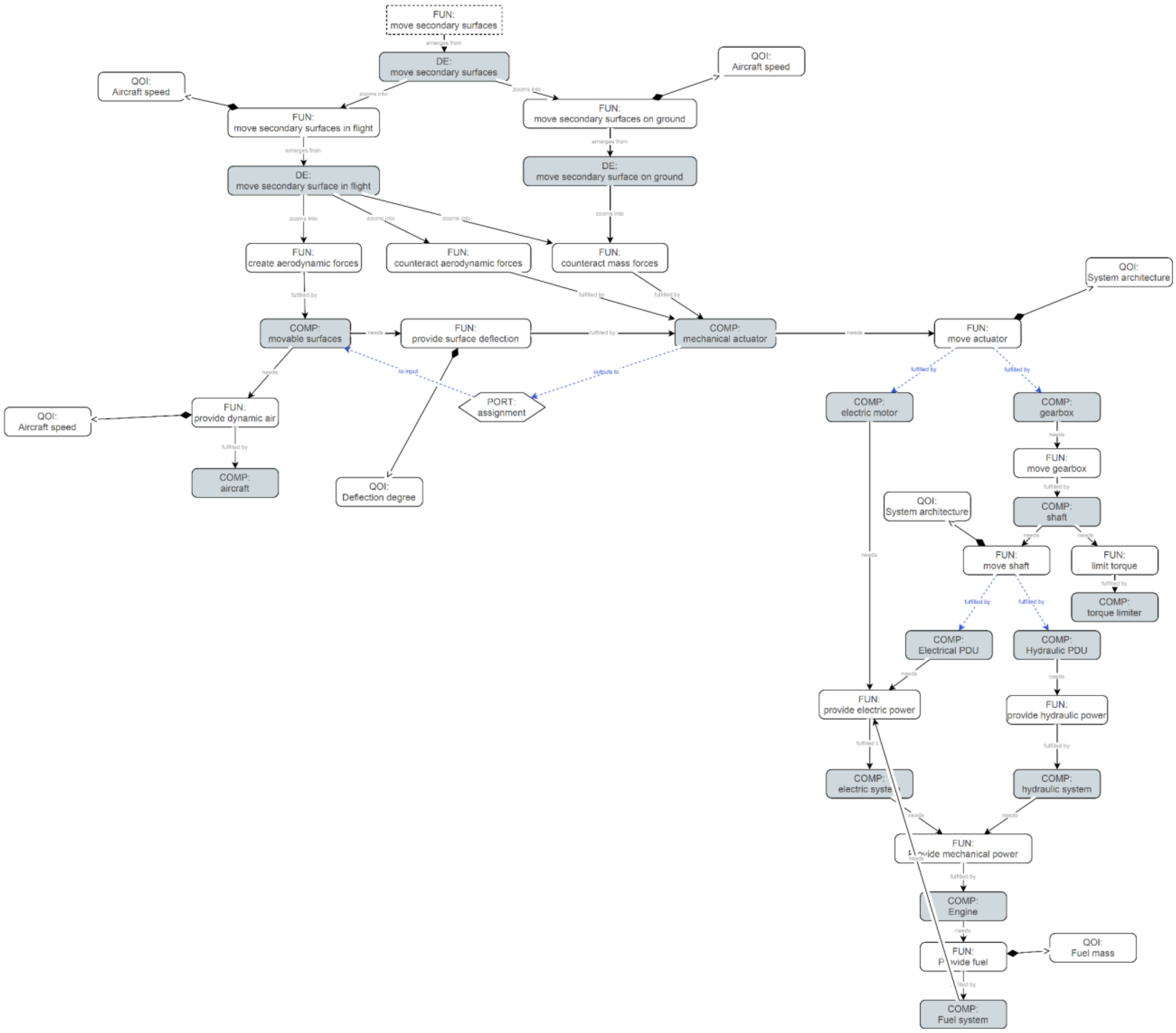


Figure 2 Architecture model of the FCS

The architecture of the FCS is quite complex when its electrification and the number and typology of actuators per control surface are considered. In Figure 3 the architecture decisions, are listed.

Project: T7.1: Systems architectures design - AGILE_4.0: Flight Control System - new*

Architecture Decisions

Search

#	Operation	Subject	Component Instance	Options
1	Fulfill function	move actuator		gearbox, electric motor
2	Fulfill function	move shaft		Hydraulic PDU, Electrical PDU
3	Instantiate component	movable surfaces		1 or 2 times
4	Instantiate component	mechanical actuator		3 or 4 times
5	Connect port	assignment		
6	Discrete design variable	FUN: move shaft -> System architecture		1, 2, 3, 4
7	Discrete design variable	FUN: move actuator -> System architecture		1, 2, 3, 4

Figure 3 AC3 OCE Decision panel (FCS architecture)

The architecture formalization and the architecture decision panel help the designer in deriving multiple architectures which could be the basis of future tradeoff studies. Therefore, a specific architecture can be defined providing a specific choice for each decision point. For instance, Figure 4 shows a specific architecture of the FCS where the following decisions are made:

- Actuator driven directly by electric motor
- One actuator per surface
- All electric On-Board System architecture.

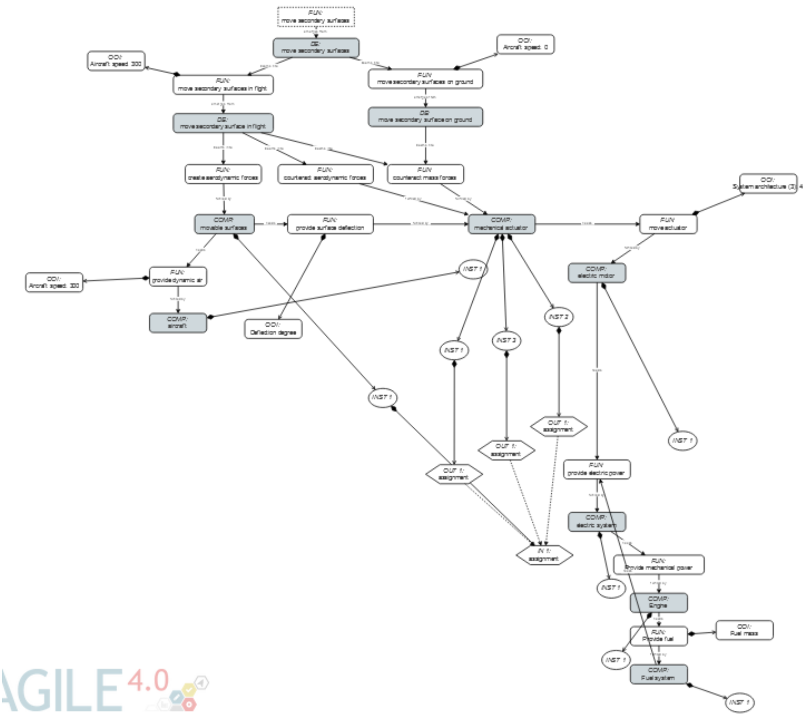


Figure 4 Specific Architecture model of the FCS

Another important system architecture to be defined is the architecture of the VCS (see Figure 5) since the main objective of this paper is to integrate certification disciplines within the MDO problem. The VCS architecture represents the integrated architecture of the tools related to certification and available within the project consortium:

- External noise certification constraints
- Minimum aircraft performance
- Systems safety assessment

There is no intention to provide a complete aircraft certification process. The main aim is to provide a good example of integration of some parts of the certification process.

The top level function "certify the aircraft" is derived from the following alternative system requirements:

"The aircraft shall comply with the CS25" or "The aircraft shall comply with the CS23". These requirements derive from the following stakeholders' needs:

- Clear certification process (Certification Authority's need)
- Entry in service before 2035 (Airliner's need)
- Low certification time and cost (Original Equipment Manufacturer's need)

As shown in Figure 5, the first splitting and decision on the main function "certify the aircraft" is related to the type of certification:

- CS 23
- CS 25

Then, these functions are developed in different ways according to the disciplines involved (i.e. external noise, minimum performance and Safety assessment) and specific regulation. Within the single tool or certification function, several sub-functions are necessary to check the design with regulation constraints.

In particular, for each certification disciplines different sub-functions are needed:

- Safety assessment: provide and then enable safety heuristic. In parallel, information about the architecture of the systems is needed to assess safety parameters
- External noise: in this case, it is necessary to estimate the external noise during takeoff and landing phase (depending on the certification type). An estimation of the noise behaviors of the aircraft is needed as well as the estimation of its performance during those phases.
- Minimum performance: the main function "verify minimum performance" is divided into two sub-function, verify climb and landing minimum performance. In turn, they are divided into the chapters defined by the regulation.

The architecture decisions panel (shown in Figure 6) lists all the main decisions concerning the VCS. Beside the regulation type (CS23 or CS25) other decisions are related to:

- Level of detail of system safety assessment (preliminary or detailed)
- Aircraft performance simulation module

In Figure 7 the VCS architecture when only the CS25 is selected.

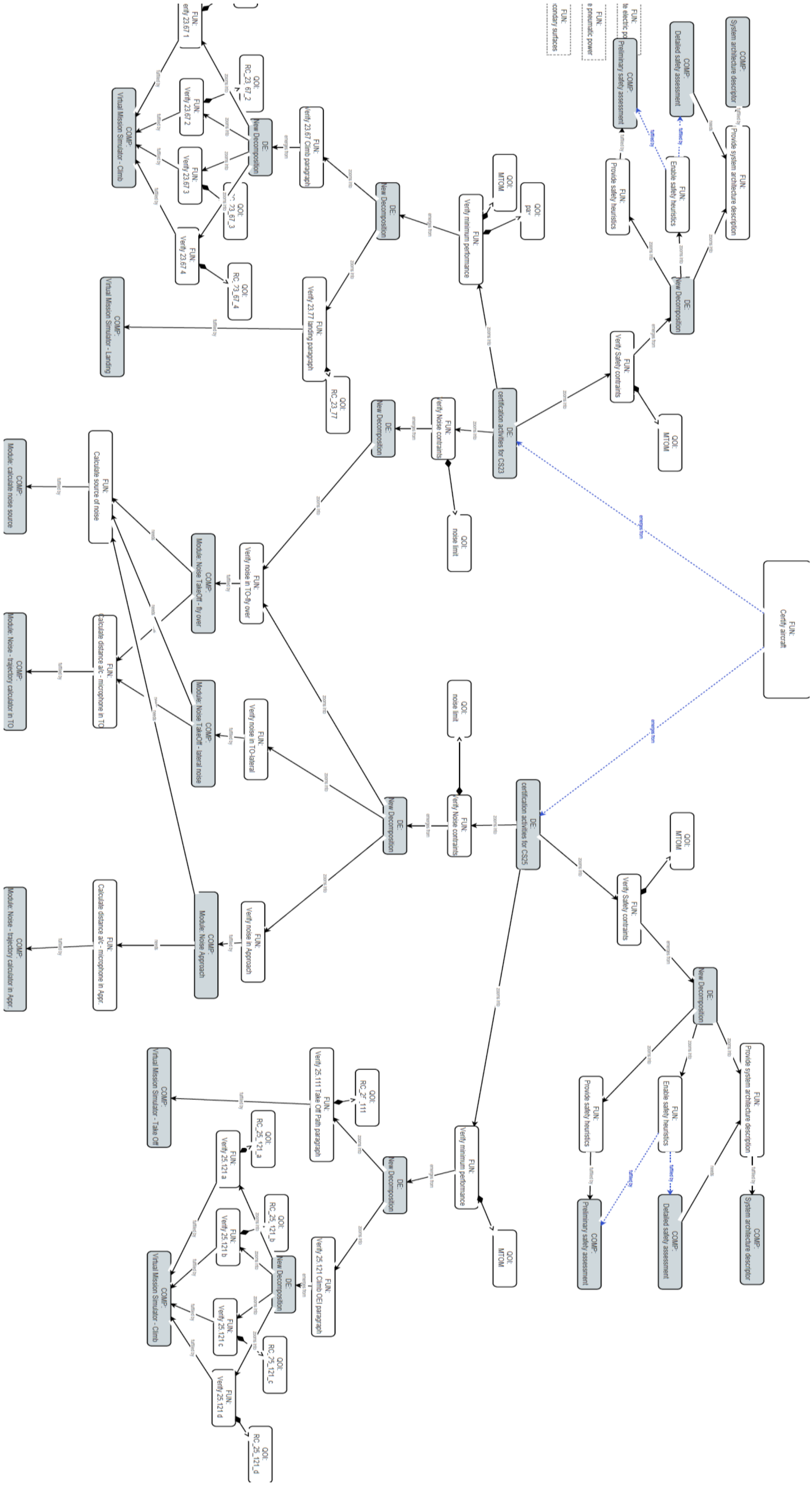
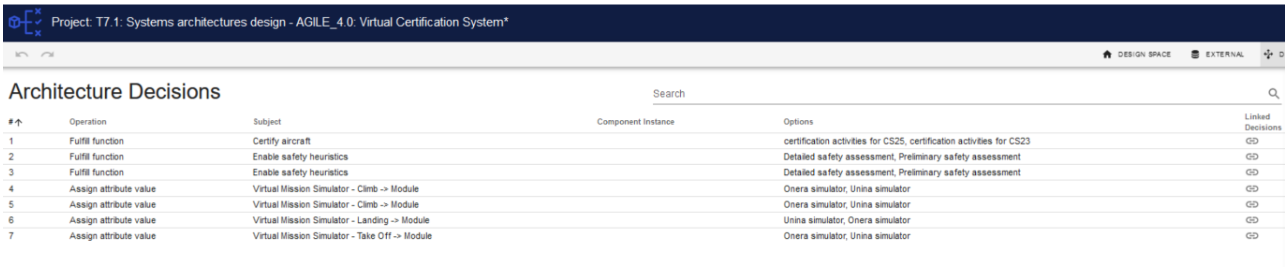


Figure 5 Architecture model of the VCS



Project: T7.1: Systems architectures design - AGILE_4.0: Virtual Certification System*

DESIGN SPACE EXTERNAL

Architecture Decisions

Search

#	Operation	Subject	Component Instance	Options	Linked Decisions
1	Fulfill function	Certify aircraft		certification activities for CS25, certification activities for CS23	
2	Fulfill function	Enable safety heuristics		Detailed safety assessment, Preliminary safety assessment	
3	Fulfill function	Enable safety heuristics		Detailed safety assessment, Preliminary safety assessment	
4	Assign attribute value	Virtual Mission Simulator - Climb -> Module		Onera simulator, Unina simulator	
5	Assign attribute value	Virtual Mission Simulator - Climb -> Module		Onera simulator, Unina simulator	
6	Assign attribute value	Virtual Mission Simulator - Landing -> Module		Unina simulator, Onera simulator	
7	Assign attribute value	Virtual Mission Simulator - Take Off -> Module		Onera simulator, Unina simulator	

Figure 6 OCE Architecture panel (VCS architecture)

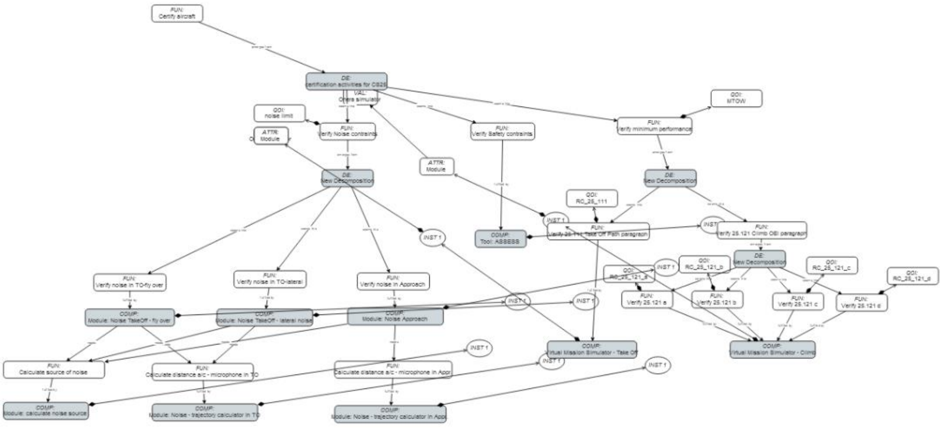
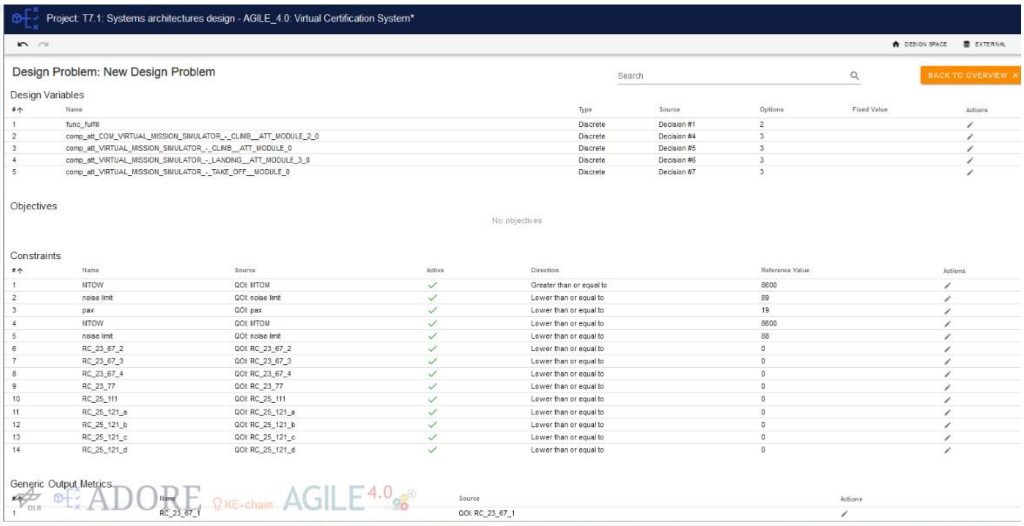


Figure 7: Specific architecture of the VCS for CS25.

Moreover, some numerical parameters have been added to the architecture as Quantity of Interest (QoI). For the VCS the Maximum Takeoff Mass (MTOM), number of passengers and the noise and performance limits provided by regulation are included in the architecture as QoI. It is then possible to define all these QoI as design variables, objectives, and constraints of the MDO problem.

In this way and as shown in Figure 8 a MDO problem could be formalized starting from the architecture. However, it may or may not represent the complete MDO problem depending on the completeness of the architecture. In the specific case of the VCS, the cost estimation that provides the life cycle cost (i.e. the objective of the present MDO) and many other parameters cannot be easily connected to the VCS architecture since they belong to a different disciplinary domains.



Project: T7.1: Systems architectures design - AGILE_4.0: Virtual Certification System*

DESIGN SPACE EXTERNAL

Design Problem: New Design Problem

Search

BACK TO OVERVIEW

Design Variables

#	Name	Type	Source	Options	Fixed Value	Actions
1	func_fulfill	Discrete	Decision #1	2		
2	comp_att_COM_VIRTUAL_MISSION_SIMULATOR_-_CLIMB__ATT_MODULE_2_0	Discrete	Decision #4	3		
3	comp_att_VIRTUAL_MISSION_SIMULATOR_-_CLIMB__ATT_MODULE_0	Discrete	Decision #5	3		
4	comp_att_VIRTUAL_MISSION_SIMULATOR_-_LANDING__ATT_MODULE_3_0	Discrete	Decision #6	3		
5	comp_att_VIRTUAL_MISSION_SIMULATOR_-_TAKE_OFF__MODULE_0	Discrete	Decision #7	3		

Objectives

No objectives

Constraints

#	Name	Source	Active	Direction	Reference Value	Actions
1	MTOW	QOI: MTOM	✓	Greater than or equal to	8600	
2	noise limit	QOI: noise limit	✓	Lower than or equal to	89	
3	pax	QOI: pax	✓	Lower than or equal to	19	
4	MTOW	QOI: MTOM	✓	Lower than or equal to	8600	
5	noise limit	QOI: noise limit	✓	Lower than or equal to	88	
6	RC_23_67_2	QOI: RC_23_67_2	✓	Lower than or equal to	0	
7	RC_23_67_3	QOI: RC_23_67_3	✓	Lower than or equal to	0	
8	RC_23_67_4	QOI: RC_23_67_4	✓	Lower than or equal to	0	
9	RC_23_77	QOI: RC_23_77	✓	Lower than or equal to	0	
10	RC_25_111	QOI: RC_25_111	✓	Lower than or equal to	0	
11	RC_25_121_a	QOI: RC_25_121_a	✓	Lower than or equal to	0	
12	RC_25_121_b	QOI: RC_25_121_b	✓	Lower than or equal to	0	
13	RC_25_121_c	QOI: RC_25_121_c	✓	Lower than or equal to	0	
14	RC_25_121_d	QOI: RC_25_121_d	✓	Lower than or equal to	0	

Generic Output Metrics

#	Name	Source	Actions
1	RC_23_67_1	QOI: RC_23_67_1	

Figure 8: OCE Design problem panel

The link between the architecture formulation and the MDO workflow definition is furtherly defined by using the MulitLinQ tool integrated within the OCE. The different QoI defined in the architecture can be linked with tools already defined in the OCE. As shown in Figure 9, each of the QoI defined in the architecture is listed in the table together with all the tools involved in the main MDO workflow. Since the VCS does not represent the architecture of the whole MDO (aircraft design and LCC estimation are not included) some tools are not linked (red columns).

Components	QOIs	ASSESS	ASTRID	Aerosurrogate	Aircraft Synthesis	Cost estimation	EngineDesign and aircraft performance	Ext_Noise	Mn_Performance	OpenAD	SFCsensitivity
Virtual Mission Simulator - Climb	RC_25_121_a								✓		
Virtual Mission Simulator - Climb	RC_25_121_b								✓		
Virtual Mission Simulator - Climb	RC_25_121_c								✓		
Virtual Mission Simulator - Climb	RC_25_121_d								✓		
Virtual Mission Simulator - Climb	RC_23_67_1								✓		
Virtual Mission Simulator - Climb	RC_23_67_2								✓		
Virtual Mission Simulator - Climb	RC_23_67_3								✓		
Virtual Mission Simulator - Climb	RC_23_67_4								✓		
Virtual Mission Simulator - Landing	RC_23_77								✓		
Virtual Mission Simulator - Take Off	RC_25_111								✓		
	MTOM		✓		✓		✓			✓	
	MTOM		✓		✓		✓			✓	
	MTOM		✓		✓		✓			✓	
	MTOM		✓		✓		✓			✓	
	noise limit							✓			
	noise limit							✓			
	pax				✓					✓	

Figure 9: VCS Mapping matrix view

4. MDAO formulation

The MDAO formulation, for MBSE purposes, can be introduced for requirements verification. Starting from the requirements already stated in the OCE, the main focus is to define an MDAO workflow (or more than one) useful to verify the requirements using the workflow results. First, the requirements have been connected to a specific design variable used by the tools (see Figure 10).

Requirements overview

Below you'll find an overview of all requirements in the design study.

EDIT

Requirement	ID	Text	Means of compliance	Test case	Validation	Responsible stakeholder	Syntax verification	Text provided	Consequence
Standard mission definition MR1	MR1	The standard mission shall be performed in 60 minutes	LoFi Analysis	verify aircraft mission performance	Valid	OEM	Yes		Lack of competitiveness
Standard mission definition MR2	MR2	The standard mission shall provide for the transport of 19 passengers at a distance of 370 km	LoFi Analysis	verify aircraft mission performance	Valid	OEM	Yes		Lack of competitiveness
Standard mission definition MR3	MR3	The standard mission shall be performed from airports with a minimum runway length of 800m	LoFi Analysis	verify aircraft mission performance	Valid	OEM	Yes		Reduced number of available airports
Standard mission definition MR4	MR4	The standard mission shall be repeated after 20 minutes	LoFi Analysis		Valid	OEM, Maintenance organization	Yes		Reduced number of flight per day
Standard mission definition MR5	MR5	The standard mission shall take place after a maximum delay of 60 minutes	LoFi Analysis		Valid	OEM, Maintenance organization	Yes		Reduced number of flight per day and high compensation penalty
		The standard mission shall be							

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Figure 10 Excerpt of the requirements list

The second step of the verification process requires the definition of test cases where the purpose and the tools involved is specified. Considering the type of requirements to be verified, three test cases (Figure 11) have been defined:

- Test case related to cost requirements
- Test case related to performance requirements
- Test case related to certification requirements

Then, each requirement has been assigned to a specific test case as reported in Figure 11 (middle column). In Figure 12 the updated list of the tools involved in the framework.

Test cases overview

Below you'll find an overview of all test cases in the design study.

ADD CLONE EDIT DELETE

Test case	ID	Means of compliance	Diagram	Design competences
verify aircraft LCC requirement		Disciplinary tool		ASTRID, OpenAD, ASSESS, +7
verify aircraft certifiability		Disciplinary tool		ASTRID, OpenAD, ASSESS, +6
verify aircraft mission performance		Disciplinary tool		ASTRID, OpenAD, SFCsensitivity +2

Figure 11: AC3 Test Cases overview

Design competences overview

Below you find an overview of all design competences in the scope of this design study

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Design competence	Function description	Model version	Input description	Output description	Input data	Output data	CMDOWS file	Import option	Level of fidelity	Average execution time (Minutes)
ASTRID	Design and analysis of the main on-board systems	1.0	moments), engine deck, aircraft main masses, mission profile, main TLARS.	systems masses, power off-takes, systems volume.	ASTRID_CPACS_INPUT.xml	ASTRID_CPACS_OUTPUT.xml		CPACS	L1: Symplified physics	5
EngineDesign and aircraft performance	Engine design and aircraft performance	1.0	Aircraft power/thrust requirements, aircraft geometry, mission profile, systems power off-takes	Engine geometry, engine mass, fuel flow	WP7_1_INPUT_for_KE-chain_CPACS_.xml	WP7_1_OUTPUT_for_KE-chain_CPACS_.xml		CPACS	L2: Accurate physics	5
SFCsensitivity	Modify engine SFC according to OBS power offtakes	1.0	engine parameters (SFC, thrust, power, fuel flow)	engine SFC values for each engine setting taking into account of OBS power offtakes	CPACS_INPUT_SFC_SENSITIVITY.xml	CPACS_OUTPUT_SFC_SENSITIVITY.xml		CPACS	L2: Accurate physics	1
OpenAD	aircraft conceptual design	1.0		aircraft geometry, main masses, thrust requirement	OpenAD_input_z0LReFX.xml	Baseline.xml		CPACS	L0: Emperical methods	1
Aircraft Synthesis	collect results from other tools and define a consistent aircraft design	1.0		consistent aircraft mass	OpenADSynthesizer-input_USK6c5t.xml	Baseline.xml		CPACS	L1: Symplified physics	0

Figure 12: AC3 Design competences overview (extract)

In order to formulate the MDAO workflow, the MDAO problem parameters should be formalized. In the OCE, this can be carried out starting from the requirements list. For each requirement that is connected to a disciplinary tool, a role can be associated. As shown in Figure 13, the requirements concerning the Top Level Aircraft Requirements (TLARs) such as the number of passengers, the aircraft speed and take off field length, were defined as constraints. The requirements related to the aircraft LCC are associated with the objective of the MDAO.

Requirement	ID	Text	Test case	Performance parameter	Problem role
Standard mission definition MR1	MR1	The standard mission shall be performed in 60 minutes	verify aircraft mission performance	Speed	Constraint
Standard mission definition MR2	MR2	The standard mission shall provide for the transport of 19 passengers at a distance of 370 km	verify aircraft mission performance	Pax	Constraint
Standard mission definition MR3	MR3	The standard mission shall be performed from airports with a minimum runway length of 800m	verify aircraft mission performance	TOFL	Constraint
Standard mission definition MR4	MR4	The standard mission shall be repeated after 20 minutes		LCC	
Standard mission definition MR5	MR5	The standard mission shall take place after a maximum delay of 60 minutes		LCC	
Standard mission definition MR6	MR6	The standard mission shall be performed from year 2035 (Initial guess)		LCC	
Standard mission definition MR7	MR7	The standard mission shall be performed at a maximum total operating cost between 1781 and 4000 €	verify aircraft LCC requirement	LCC	Objective
Standard mission definition MR8	MR8	The standard mission cruise phase shall be performed at altitude greater than 7500 meters	verify aircraft mission performance	Ceiling	Constraint
Standard mission definition MR9	MR9	The standard mission shall be performed with a probability of catastrophic event not greater than 1/10^9 flight hours	verify aircraft certifiability	Certification cost	Objective
Standard mission definition MR10	MR10	The standard mission shall be performed from airports provided with the reference hangar dimensions		LCC	Constraint
Standard mission definition MR11	MR11	The standard mission for electric variant of the aircraft shall provide for the transport of 9 passengers at a distance of 555 km	verify aircraft mission performance	Pax	Constraint
System requirement R1	R1	The aircraft shall perform the standard mission in 60 minutes		Systems electrification	
System requirement R2	R2	The aircraft shall perform the standard mission at 0.45 Mach average speed	verify aircraft mission performance	Speed	Constraint
System requirement R3	R3	The aircraft shall transport 19 passengers at a distance of 370 km at standard mission	verify aircraft mission performance	Pax	Constraint
System requirement R4	R4	The aircraft shall operate from airports with a minimum runway length of 800m	verify aircraft mission performance	TOFL	Constraint

Figure 13 Requirements role definition

As shown in Figure 14, the parameters of the MDO problem are formalized. Each of them is traced to the requirement and connected to the specific CPACS variable.

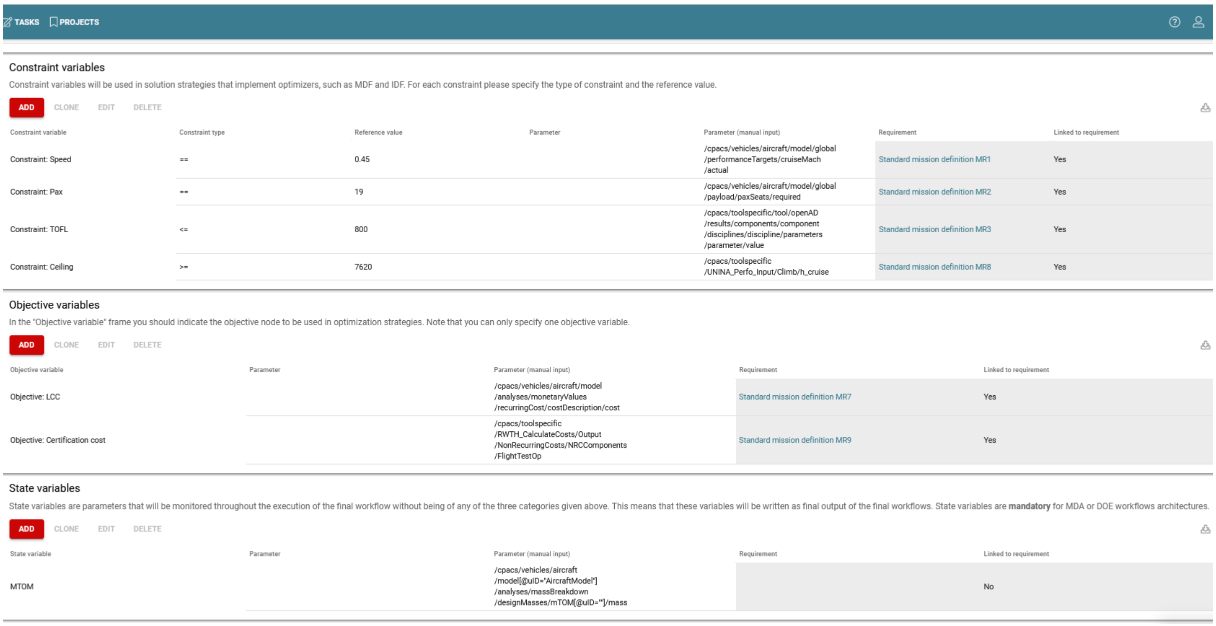

Figure 14 AC3 MDO parameters formalization

Considering the tools involved in the different test cases for requirements verification a MDO workflow can be defined. In Figure 15 the MDO workflow necessary to verify the LCC requirements is shown. Since the LCC is influenced by all the disciplines involved, the workflow is the most complete.

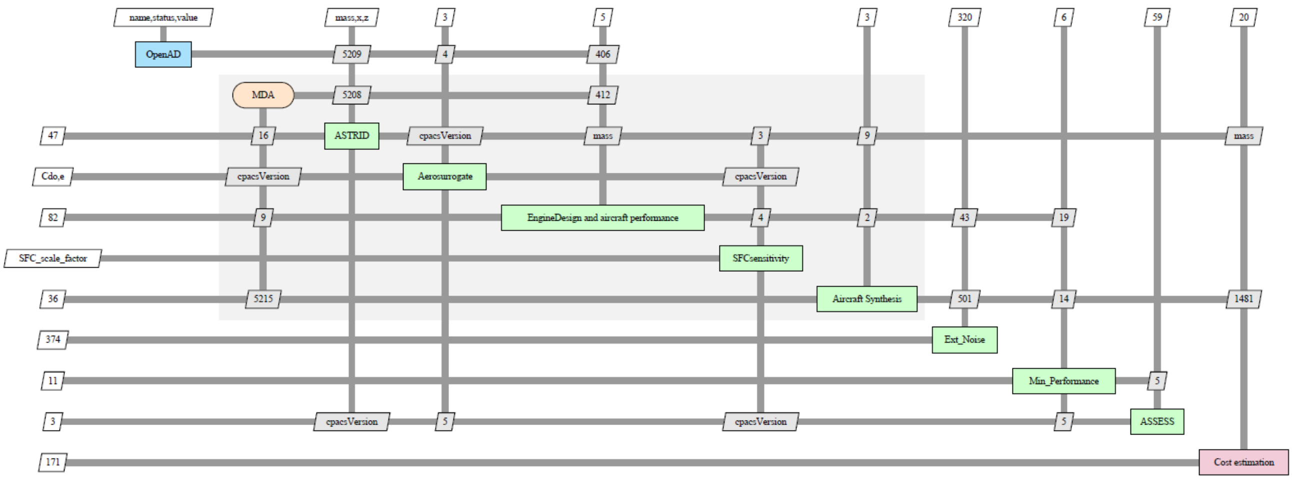

Figure 15: MDAO XDSM

5. Conclusions

The MDAO of a small turboprop aircraft has been successfully implemented using the adapted MBSE models. The OCE technologies have simplified the MDAO formulation process formalizing the connection between MDAO parameters and tools. The OCE added the capability of fully tracing the requirements from their definition to their verification. In particular, the connection of the MDAO and requirements’ parameters with the CPACS file is a powerful option to actually enable the connection between problem formalization and the design activities. Considering the problem complexity (i.e. complete aircraft design) not all the possible architectures and aircraft part are here implemented however, the OCE proved to be an essential tool for reducing the development time of complex systems.

6. Copyright Statement

7. Acknowledgments

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