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THERMAL TRADE OFF SUSTAINED BY MULTI DISCIPLINARY AND MULTI LEVEL OPTIMIZATION

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Abstract. *Evolution toward more complex electrical systems on board of commercial aircrafts to be fitted in smaller containment areas of composite lightweight structures have raised challenges in respect of thermal optimization in a multi-disciplinary context. It is so crucial to OEMs that it motivated the assembly of a consortium from 32 companies around an R&D project, named "Thermal Overall Integrated Conception of Aircraft" under the umbrella for Framework Program 7 with a focus on:*

- *Closing the gap between architectural view and domain specific simulations*
- *Enabling multi-level, multi-disciplinary approach for flexible architecture trade-offs*
- *Developing new integrated architecture aiming to thermally optimize aircraft*

Among others activities along this project, MSC is engaged to sustain one of the selected use cases conducted by Airbus and referenced here as new power plant integration.
Specifically, an environment enabling architects to conduct a trade-off study collaboratively with domain specialists has been developed. It is tightly integrated with Airbus simulation environment built on the top of heterogeneous solutions from Siemens, Cenaero and MSC. TOICA outcome so far have focused on:

- *Trade Study Process Management capitalizing on former projects developments like the "Modeling and Simulation information in a collaborative Systems Engineering Context" (MoSSEC) introduced in Crescendo*
- *Multi-Level and Multi-Disciplinary Optimization tightly linked to the concept of agile behavioral model generation*

This paper exposes maturity of the proposed solution validated by real plateaus execution involving all actors of the targeted study.

1 INTRODUCTION

Among critical capabilities required by architects and chief engineers, managing efficient trade-off studies of thermal energy has become a number one priority. The efficiency and management are needed because the aircraft manufacturers work collaboratively with their extended enterprise to propose competitive solutions.

Indeed, if early evaluation of more alternatives is key to avoid late recognition of "low-performing" design solution and facilitate faster time to market demands, then better understanding of the thermal behaviour has emerged because of the growth of inter-related challenges at sub-component level:

- Shift from hydraulic and pneumatic systems to more electrical ones in modern aircrafts has highly affected the overall thermal load; the thermal load has increased five-fold over the two last decades. No reduction in such a trend being expected for the foreseeable future.
- Further, confinement of equipment to address payload increase (cargo and passengers) has raised issues related to sensitivity of new generation batteries to ambient temperature.
- Effort to lighten Aircraft Structures through use of composite materials, whose insulation power is higher by 2 orders of magnitude, created more thermal constraints. However, the mechanical properties of composites might also drop drastically beyond their glass transition temperature. The gap between composite and thermal expansion coefficients can also induce critical constraints at the junctions of some components assembly.

To overcome these thermal challenges, it is key that the aerospace industry performs thermal trade management as early as possible in the development process. Therefore, a consortium of 32 companies, coordinated by Airbus, launched an R&D project, named "Thermal Overall Integrated Conception of Aircraft" (TOICA [8]) that has been awarded for funding by the European Community's Seventh Framework Programme (FP7/2007-2013, under grant agreement n°604981).

The focus of this project is on:

- Closing the gap between architectural view and domain specific simulations validation
- Enabling multi-level, multi-disciplinary approach for preforming flexible architecture trade-off analyses.
- Developing new integrated architecture/solutions aiming to thermally optimize aircraft

Among the partners and their associated contributions:

- Airbus leads several Use Cases and drive their implementation through "plateaus". Plateaus are technical working sessions where thermal trade-off studies are operated using the TOICA capabilities and where business benefits are assessed.
- MSC contributes to the development of TOICA capabilities like:
    - Specific Aircraft Architect Environment to empower the architects with means of assessing their architectures in early design phases, through trade-off studies and reviews.
    - Collaborative data and process management capitalizing on previous project outcomes like Behavioural Digital Aircraft matured by CRESCENDO.
    - Parametric Model Generation to enable end users to build objects serving as inputs in studies of configurations and their evaluations along trade off process.

  - Coupling simulation approaches in Multi Discipline and Multi-level context.

This paper intends:

- To share the status of the proposed methods, elaborated with partners using Technology Readiness Level, reviewing Airbus's use case relative to Pylon Architecture trade-off for new power plant integration.

  Specifically, the TOICA collaborative richness will be described showing how the Flexible Model Generation capability, capitalizing on Pyramid of Model and Super Integration concepts, is used either to address needs of the simulation experts or as a trade-off generator engine serving the architect platform.

  MSC, as work package leader, is coordinating the Flexible Model Generation capability; Siemens/LMS is orchestrating the Pyramid of Model concept.

- To map the proposed methods to TOICA use case driven by Airbus and focusing on management of power plant integration trade off from a multi-disciplinary perspective.

2 TOICA AT A GLANCE

TOICA is a 3-year European project, coordinated by Airbus that was launched in 2013. Its contributors comprise a consortium of 32 partners from 8 countries associated with a budget of nearly 30M€.

R&D effort is balanced amongst eleven industrial companies, seven IT vendors, five small and medium enterprises, four research centers, and five universities.

Capitalizing on results (Figure 1) of the CRESCENDO European project (2009-2012), where the concept of the Behavioural Digital Aircraft (BDA, now referred to as the MoSSEC standard [7]) architecture was specified, developed and validated, TOICA aims to introduce the next generation approach to sustain aircraft thermal studies throughout the design cycle. The proposed path is to develop simultaneously the systems, equipment and components by utilising the exchange of their behavioural representations amongst the stakeholders.

In that respect, the TOICA members have agreed on four High Level Objectives (HLO):

- HLO1: Develop customized collaborative simulation capabilities improving the generation, management, and maturity of the BDA dataset.

- HLO2: Develop new concepts for improved thermal load management within aircraft components, systems and equipment, which will integrate innovative cooling technologies and products.

- HLO3: Assess and validate the developed capabilities and technology concepts against different common reference aircraft targeting both "Enter into Service (EIS) 2020" and EIS 2030+ Thermal Concept Aircraft".

- HLO4: Optimise aircraft design by enabling highly dynamic allocation and association between requirements, functions and product elements (Super integration) for product innovations.

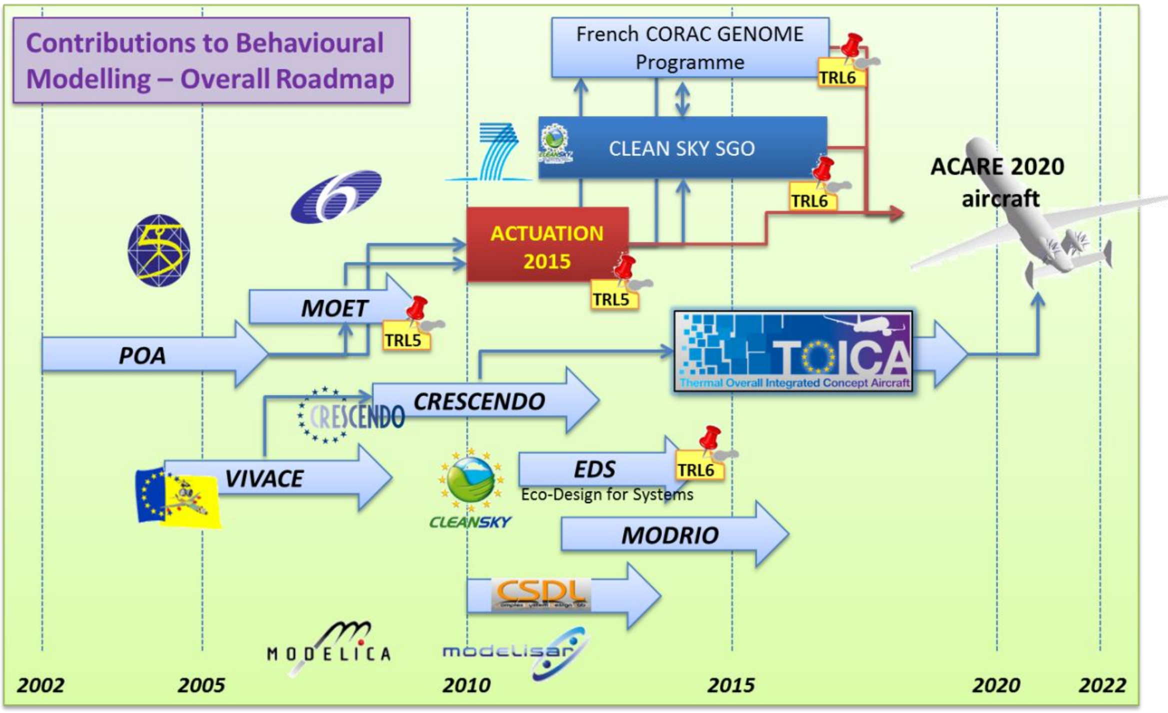

Figure 1: TOICA History

In order to deliver applicable results on time, TOICA relies on its Use Case driven organization; with a progress monitoring scheme derived from a realistic aircraft design cycle that is drum beat by regular Milestone plateaus (MSP). In other words, real actors, in the context of their design activity, test any capability developed, which allows them to check a proposed method and review its Technology Readiness Level (TRL) validation. Further, it allows them to evaluate the gap between the expectations and the evidence produced.

Six main use cases, illustrated in Figure 2, have been retained:

- Manage Future Aircraft Architecture
- Integrate Equipment Thermal
- Research new cooling Technologies
- Manage Aircraft Heat Load via Heat Sink
- Optimize Overall Thermal (Energy) for Systems
- Integrate Power plant

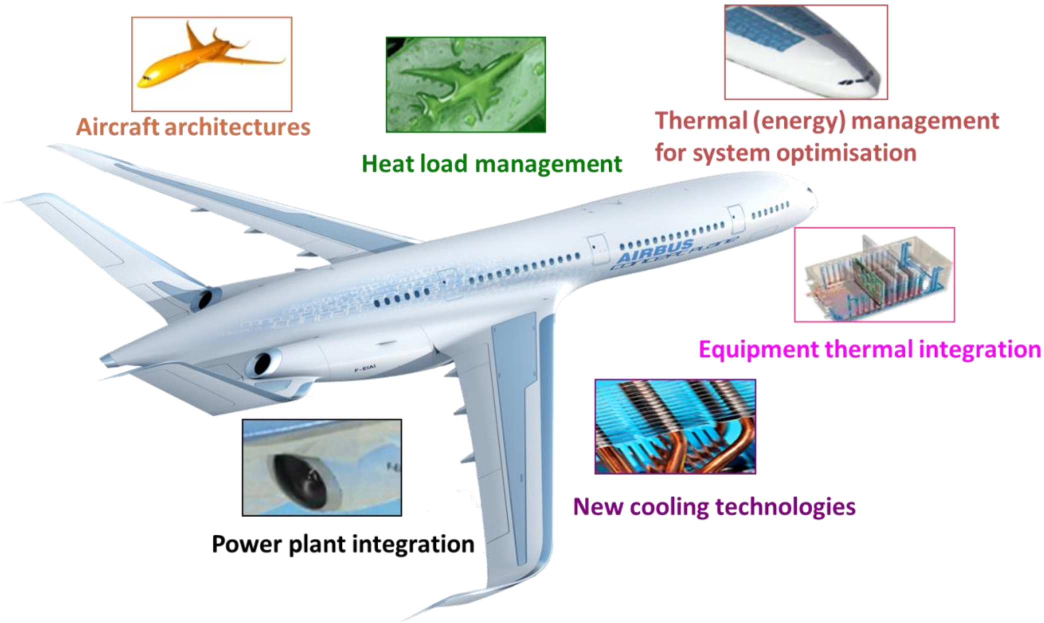

Figure 2: TOICA Use Cases

TOICA partners target to contribute to “Challenge 3 – Competitiveness through innovation” of the ACARE SRA2 High Level Target Concept (HLTC) “High Efficient Air Transport System”, enhancing:

- Aircraft development cost
    - Reducing by 10% equipment development impact via a more robust specification process allowing equipment supplier, or risk-sharing partners, to design systems and equipment according to more realistic margins.
    - Reduce the costs and time associated with integration and installation of systems and equipment in aircraft by strongly reducing the need for late rework
- Supply chain efficiency
    - Reduce by 50% the lead time of an aircraft thermal architecture assessment.
    - Shorten by 6 months the equipment development process by improving the exchanges of thermal requirements with the suppliers and sharing the overall thermal view information across the supply chain.
- Aircraft operational costs:
    - Reduce by 5% the energy/power consumption used for active cooling or controlling (heating) of systems
    - Increase the Mean Time Between Failure (MTBF) by 15% as the direct impact of more equipment-dedicated specifications

In the following chapter, we focus on a specific study related to the future architecture associated to Airbus New Engine Option (NEO). For the sake of this study, we will pay special attention to TOICA developed capabilities: Architects’ Cockpit, and Flexible Model Generation. We will highlight how the overall study is already benefiting from the MoSSEC standard [7] and the multi-level coupling, mechanisms. Finally we will elaborate on how it will be fully delivered using additional TOICA developed capabilities like Super Integration.

3 NEO USE CASE

3.1 Business Challenges and benefits

Maximum re-use of equipment is expected in order drastically reduce program development costs.

However, for various reasons like hotter engine and reduced space allocation the thermal environment of equipment, thermal constraints on new configuration raise. This trend is even accentuated by new nacelles and engines design orientations like:

- Increase of the engine by-pass ratio impacting cooling efficiency
- Shorter nacelles impacting space allocation
- More electrical function generating more heat sources.

This leads to a strong need for efficient thermal trade-off means of equipment, required to face such an emergence of thermal challenges.

The required capabilities to be delivered by TOICA should:

- Enable early trades on power plant and pylon integration considering thermal integration & ventilation as well as re-use of constrains.
- Enable trade on bleed architecture that includes all the driving parameters: ventilation, thermal impact and exhaust section, bleed performance, etc…
- Analyze the close aero-mechanical-thermal coupling impact to pylon design.

3.2 Trade off scenario

In this case, the evolution of the aircraft configuration follows a process composed of the following key steps:

- Define Top level aircraft requirement;
- Define Mission;
- Derive Neo Power Plant architecture constraints from aircraft baseline including
    - Aircraft level requirements
    - System level design requirements
    - Functional definition
    - Baseline architecture definition
- Analysis at aircraft and system level of the baseline configuration
- Review and challenge of the baseline configuration
- Evolve the configuration in a iterative process

In particular, the introduction of baseline variants or alternatives hypothetically takes place during the review and leads to the evolution of the configuration.

The evolution of the configuration will generate a variant dataset, linked to the baseline dataset to ensure traceability of the entire evolution process. This is because the dataset is linked to the configuration

Specifically, as shown in the workflow views reported above, the main actors' interactions with the dataset can be summarized as follows:

- Power Plant Architect: Defines the trade-off study He specifies the study objectives and populates the dataset by creating/importing the
    - TLAR
    - Operational definition
    - Aircraft configuration and zoning
    - Objectives
- Thermal Expert: Receives the study request from the Power Plant Architect and enriches the dataset by defining the thermal objectives and constraints before to split the request in two branches:
    - The first one, the analysis of cooling and packing of engine integration compartments
        - In turn this sub-study will involve additional actors like the Engine Architect and his thermal team, at integrator partner's level.
    - The second one, relative to pylon thermally constrained design trade off
        - Equally to the previous one, this branch will grow into a distributed and collaborative study coordinated by a thermal leader

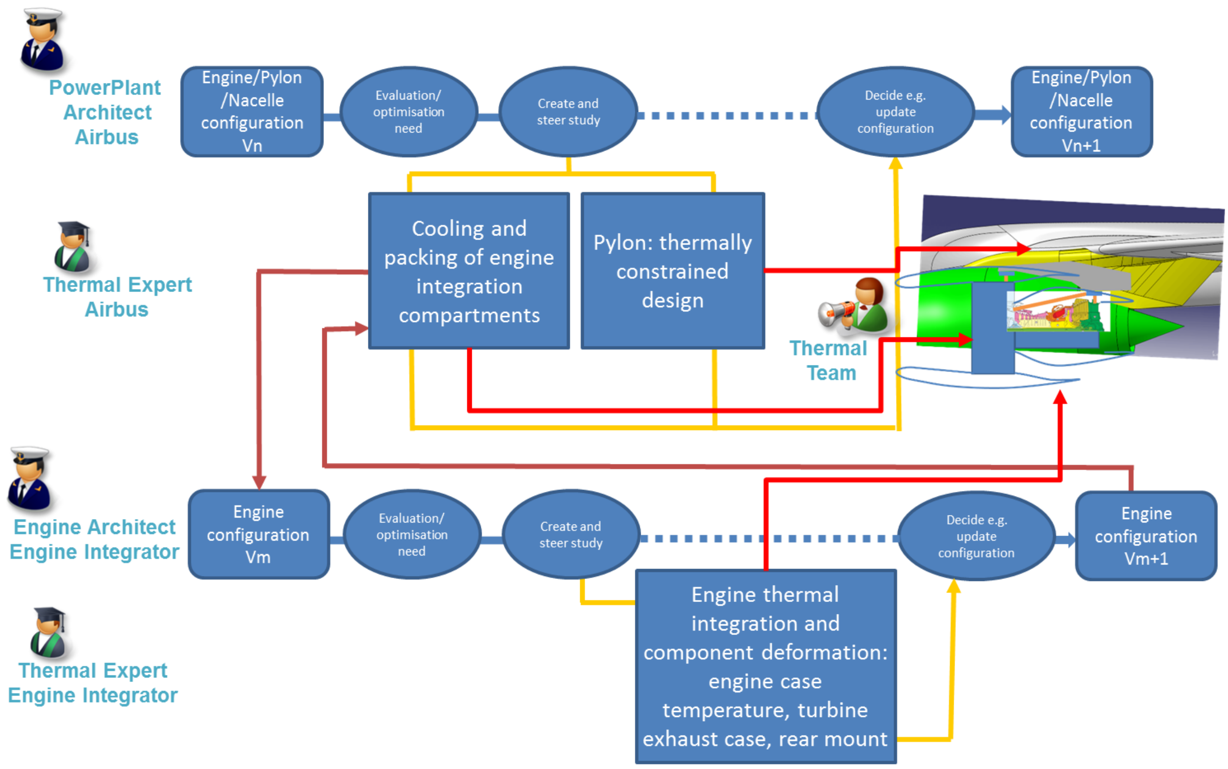

Figure 3: TOICA Neo Use Case Scenario

The sub-study dedicated to pylon trade-off will be detailed along the next paragraph to illustrate how thermal expert will leverage most of the TOICA developed capabilities to collaborate with the architect. This expert will orchestrate a multidisciplinary and multi-level optimization process for the engine pylon, where this process takes into account thermal, flutter and detailed stress constraints (Figure 4).

The goal in that case being to assess the sensitivity of the main performance indicators with respect to variations of the pylon width along three different of its sections. The considered performance indicators will be mass of the pylon and the drag coefficient; proposing a set of design solutions that are optimal in the sense of both aerodynamics and structure disciplines.

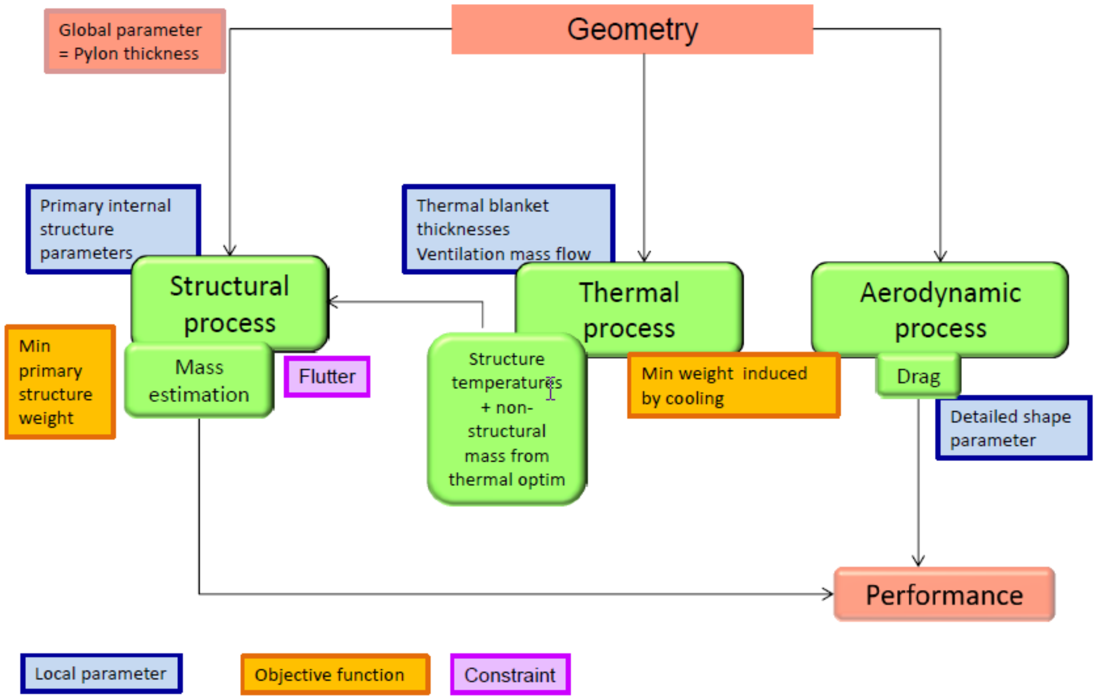

Figure 4: Multi-Disciplinary scenario overview

Technically this will be reached by leveraging a bi-level approach:

- At global level: each discipline feeds the global process with shared parameters (pylon width, material choice…), constraints and objectives (minimum drag and mass).
- At local level: specific parameters and constraints for each discipline are addressed, and are not shared among the disciplines.

3.3 To-Be process requirements mapping to TOICA capabilities

In order to address the business objectives defined in 3.1, the "As-Is" process needs to be enhanced in a way that the workflow, highlighted by Figure 3, can be executed by the actors.

Initial requirements direct us to an environment where the architects can (Figure 5)

- Define their domain architecture at aircraft level, (the Power Plant level in the specific case of TOICA), or at Engine Integrator level. Forthwith these objects are called models because:
    - Conceptually they are supported by the idealization from various perspectives, being for instance functional; logical, 1D to 3D views.

    - Such models are essentially assembly of sub-models: from the requirements and objectives within an operational scenario to physical representations that can co-exist at different levels.

- Edit/Author the architecture model, meaning:
    - Populating datasets for a certain view
    - Updating view representation while development matures
    - Deriving alternatives from a baseline, or an existing library of architectures. At this stage, it corresponds to trade variable definition converted to parameters of the architecture model, where a parameter can encompass many representations like
        - Geometrical (change of a dimension or a zone)
        - Functional (choice in function to perform)
        - Architectural (requirements & objectives balance scope)
        - Behavioural (selection of Idealization level & method to assemble possible components of overall object)
- Explore a proposed architecture through visualization of the
    - Requirements space (requirements, objectives, constraints)
    - Alternatives, as an initial means of comparison
- Instantiate and manage trade off request from previous variants:
        - Defining and distributing tasks to various stakeholders across the extended enterprise; while retaining Intellectual Property Rights in the context of heterogeneous domain tools and infrastructures.
        - Monitoring based on selected key indicators throughout the project by tracing
        - Assumptions
        - Uncertainties
        - Results
        - Decisions

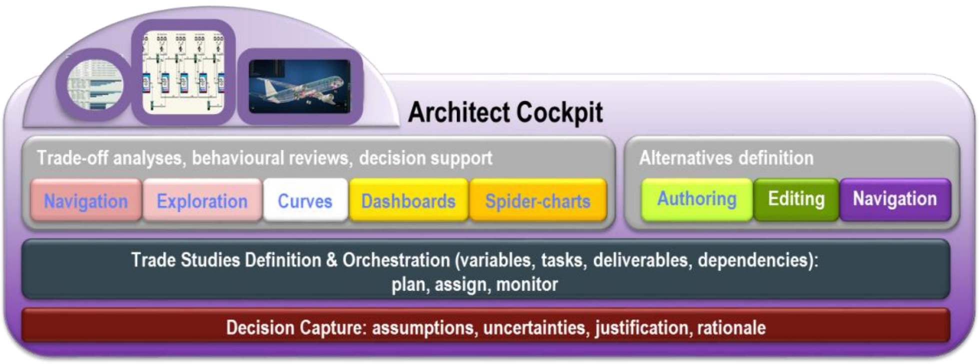

Figure 5: Architects’ Cockpit functional scope

Beyond natural interest into an Architects' Cockpit from the NEO scenario, two additional TOICA developed capabilities will consolidate the benefits delivered to the end users. In the latter scenario, many stakeholders are engaged in a collaborative effort. The foreseen deployment does anticipate multiple lifecycle management platforms (Airbus legacy and /or partner's heterogeneous infrastructure constraints). Therefore, the communication and exchange scheme with the extended enterprise require some level of standard format and services to work collaboratively with them. In that respect, TOICA contributes to the MoSSEC [7] standard, by working on necessary BDA objects expanding the thermal collaborative scenario that were already validated during CRESCENDO project [1].

Keeping in mind the Architects' Cockpit requirements, and switching to the Modeling and Simulation (M&S) toolbox, it is now easy to understand why and how it has to be "powered inside" with Flexible Model Generation technology. Indeed, its purpose is to enable the assembly of componentized models: what an architecture definition is; and to introduce parameters to enable creation of variant models: what a tradeoff requires.

At such a stage, we do not even need to know what the sub-model components will be. Their representation will be populated with richer models while the development cycle of the aircraft progresses. In paragraph 3.4, we will show examples like top-level aircraft requirements (TLAR); operational scenarios, functional or system models and surrogate simulation models or 3D CAD models. However, at this stage it is important to emphasize that if Flexible Model Generation allows you to select a sub component and/or parameterized it along the global model assembly, it does not affect the possible choices among level representations.

Indeed, if a choice does not exist at the start of the aircraft project it is important to organize the way we make a particular choice when several options become available. Do I select a surrogate representation of the structure, or a full 3D model? Does a 3D model derives from a preliminary simplified representation, or vice versa: surrogate versus 3D is not only a difference in the maturity of the study; it can be a preference in respect of the analysis performance associated with the precision on the expected result. The M&S workgroup in charge of this capability has developed the Pyramid of Models organization that can be seen at process-oriented libraries of models that the Flexible Generation aspect will query when a possible choice occurs.(Figure 6)

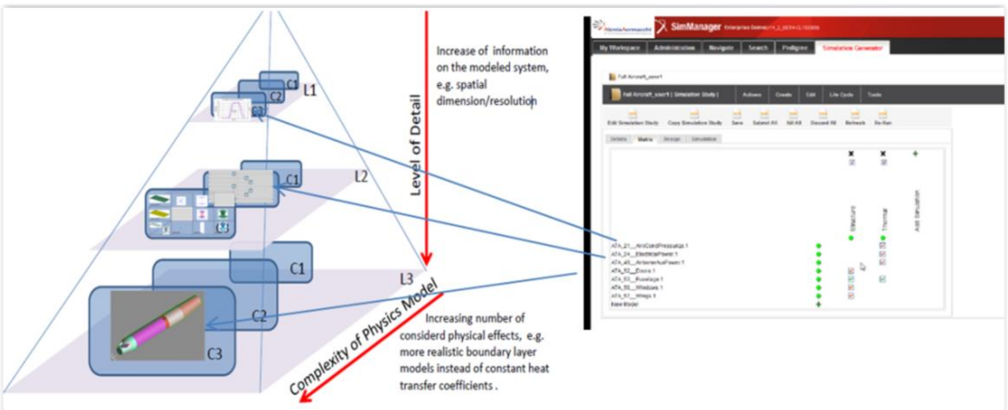

Figure 6: Pyramid of Models Serving the Flexible Model Assembly Generation

This coupled solution enables framework of model usage to sustain NEO scenario with the Multi-Disciplinary architectural/behavioral representation of the complete aircraft, in any operating conditions.

During the implementation of NEO use case detailed in this paper, we will see a second aspect of Flexible Model Generation directly applied to a more commonly understood geometry parameterization, driving a parametric simulation model. In that respect TOICA has capitalized on methodology introduced by Airbus and enhanced in a European project from framework program seven named MAAXIMUS [3].This approach is to use external shapes and add Design Parametric Objects (DPOs) of structural components like, ribs, holes, stiffeners or corners piece reinforcements

Then for each DPO an excel design table (DT) is created with associated parameters and each parameter of the DTs can be linked through excel with others if needed, or with parameters associated to an external shape and logged into an xml format.

Diving more into the details: we know that the scenario has to be driven by a Multi-Disciplinary Optimization (MDO) and Multi-Level as well as accounting for optimization and coupling aspects, using the TOICA M&S capabilities. We will not elaborate this optimization method because it is covered by a “conventional” Design of Experiment approach. Therefore, we focus attention to the fashion in which simulations are coupled.

Indeed, we have already described benefits of Flexible Model, assembling components from libraries organized as a Pyramid of Models. What we have dropped so far was the magic to make dissimilar idealization components compatible for the execution of a coupled run. In the context of NEO such integration has been performed by the creation of behavioural libraries and surrogate models that will enable exchange though “MoSSEC” connectors. This “interface” component, in the generation of the model, becomes one of the possible “variability” or parameter of the Flexible Model. It means here that if Architect view of the aircraft is:

- Pylon Structure +Interfaces+ Equipment + Operational Scenario

The representation for a simulation of a trade study can be for instance upon choice of equipment partner’s CAE preferred domain tools:

- Pylon Structure(Solver A) + Interface (Solver A to B) + Equipment(Solver B) + Loads &Boundary Conditions
- Pylon Structure (Solver A) + Interface (Solver A to C) + Equipment(Solver C) + Loads & Boundary Conditions

As we need to enlarge Flexible Model to the concept of Architectural Model, the method needs to sustain not only coupling of models via an “interface component” but also functional models for which one change is going to impact more than, for instance the definition of model itself (more electrical components…) . Flexible Model will then be supported by Super Integration, which will be demonstrated in future TOICA plateaus.

Finally, we will close this presentation of TOICA capabilities complementarity, as well as their mapping to the use case needs pointing onto risk reduction one. It is the final touch to empower stakeholders and ultimately architects to trace information and decision associated with the KPIs.

3.4 Scenario implementation example

Consistently with capability mapping, the cornerstone component of the scenario implementation has been the Architects’ Cockpit. Choice has been made on MSC SimManager interacting with SimManager as the SLM for the pylon multi-disciplinary trade-off and another PLM technologies representing legacy or extended enterprise platforms. This will enable the demonstration of TOICA collaborative philosophy, throughout the exposure of a communication to a SimManager server across APIs that are MoSSEC compliant, as demonstrated in CRESENDO [2]. Then a key core product functionality known as “Assemble&Simulate” that enables in the simulation context to glue model components together for a particular simulation scheme(parts idealization, connectors ,loads, constrains, materials, solver parameters, key results to extract, report to generate) before to automatically submit a job and retrieve the outputs, has been extended to an “Assemble&WorkRequest”. As such it is behaving in the same way in respect of an architecture model to define, populate with datasets and associate to a trade study, requests to be sent to other actors.

Knowing that SimManager work request are by design mapped to MoSSEC model network representation, the solution can be implemented in a context of the extended enterprise for which the trade study demand is conveyed then to the partner by a MoSSEC web service.

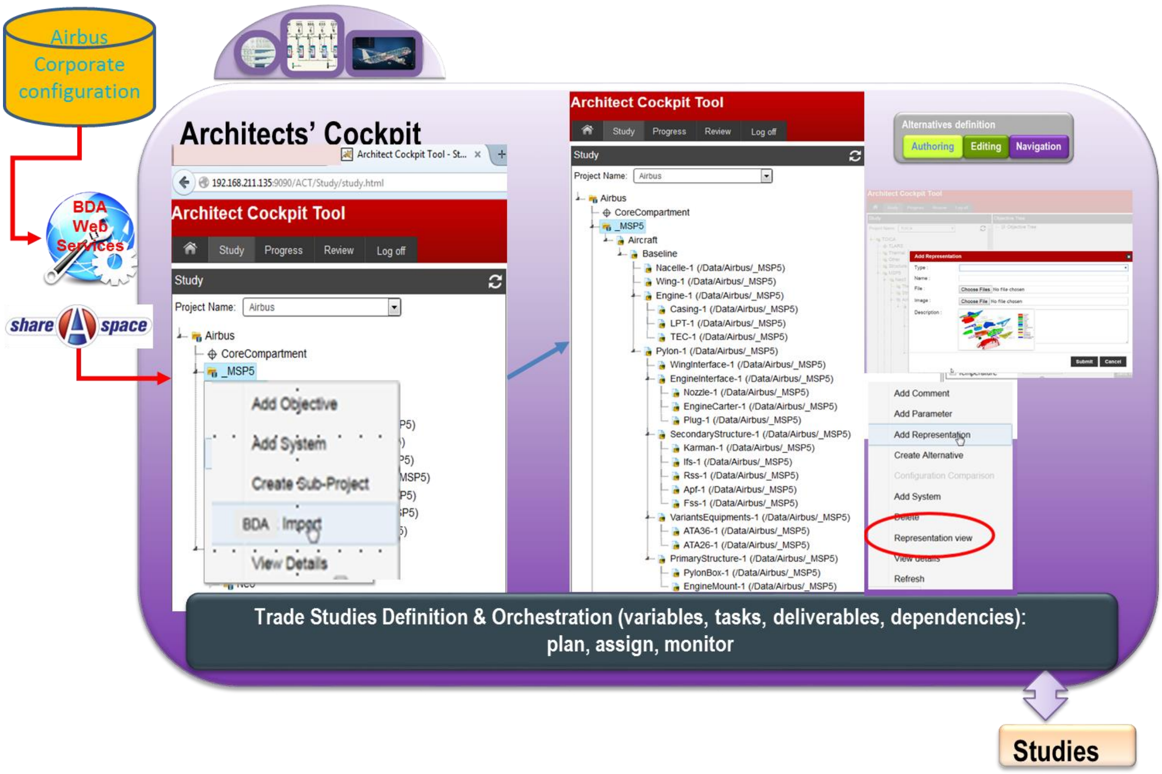

Figure 7: Illustration of Architects’ Cockpit leveraging Flexible Model Assembly from functional architecture vs scenario

Representation can be updated by right clicking on a model component in order to browse the “MoSSEC” libraries (Pyramid of Model & Super Integration) and select the preferred available level to be used in the study. User interface also allows for variant generation for instance by dragging and dropping an existing instance prior to define the variable parameters and update the master consequently. (Figure 7)

Same kind of sequence is applicable to any layer of architects in the scenario, knowing that each time a request is made to actors, a notification is send which allows next stake holder to update the detail of the model in respect of its domain of concerns.

And finally, Architects’ Cockpit will monitor study request execution, checking each task status (pending, running, completed, aborted…) in respect of planning. Each task can report objects, returned to the requester by the actor in charge of a particular aspect of the study. Of course, a result (temperature, width impact…), or a report of combined information can help to sustain a documented decision, in between additional milestone feedback like validation gates can also be controlled. Knowing that communication here again is managed by

MoSSEC associative model network (AMN) [2], it is possible to sink two activities with a filter on the granularity of details, and the representation of information exchanged.

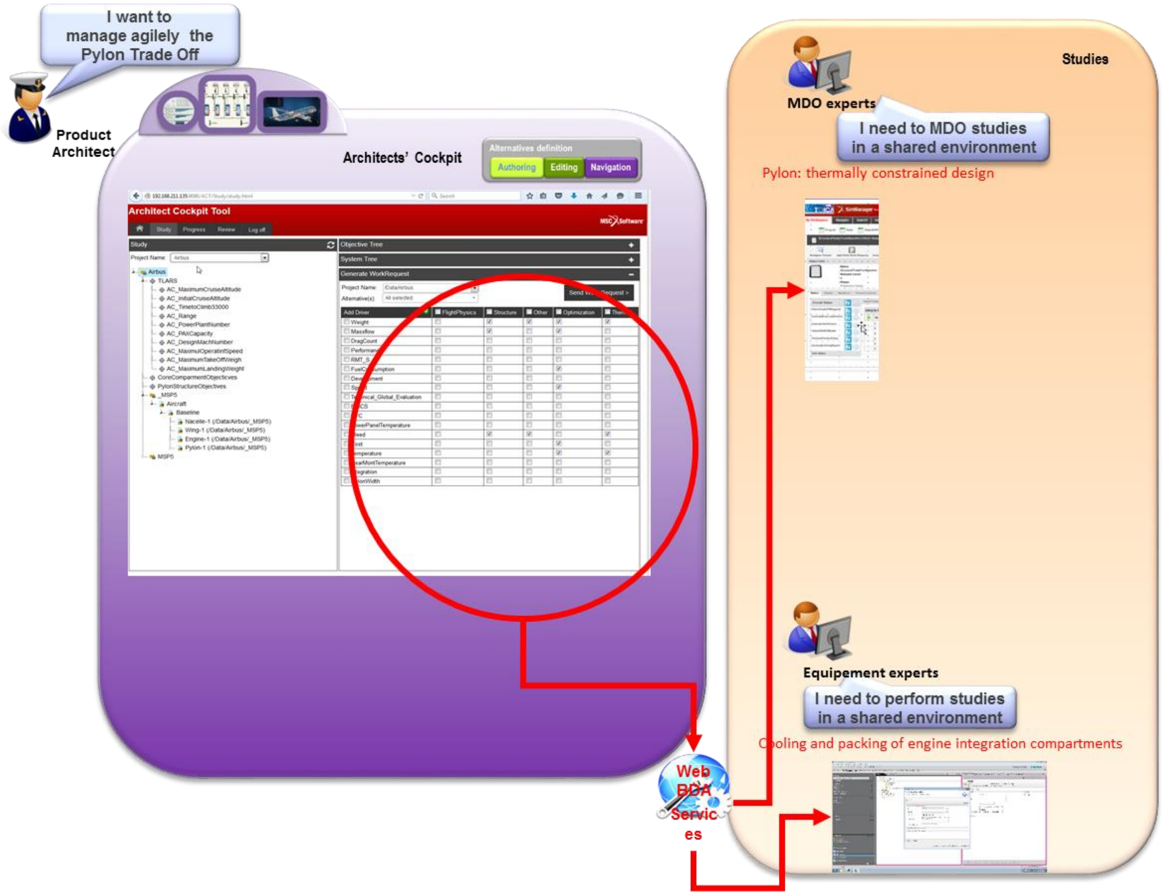

Figure 8: Multi-Level process granularity from Architects' Cockpit to SLM

The first use of AMN allows architect to safely trace simulation expert answers without any burden on CAE domain know how has shown in Figure 8, while the second way of use empowers Intellectual Property Right preservation by the mean of behavioral representation along the collaboration.

The second enabler, we will detail is the Flexible Model Generation applied this time to Simulation domain. In order here to address need for multiple variant on a geometrically parameterized model, we have developed around MSC SimXpert, a tool that can (Figure 9):

- Read an aircraft geometry and associated parametrization relying on DPOs as introduced in chapter 3.3
- Leverage the Airbus patented ways in associating them to Parameterized Geometric Support (PGS): a child CAD model of the DMU associated to DTs representing part of the physics [5].

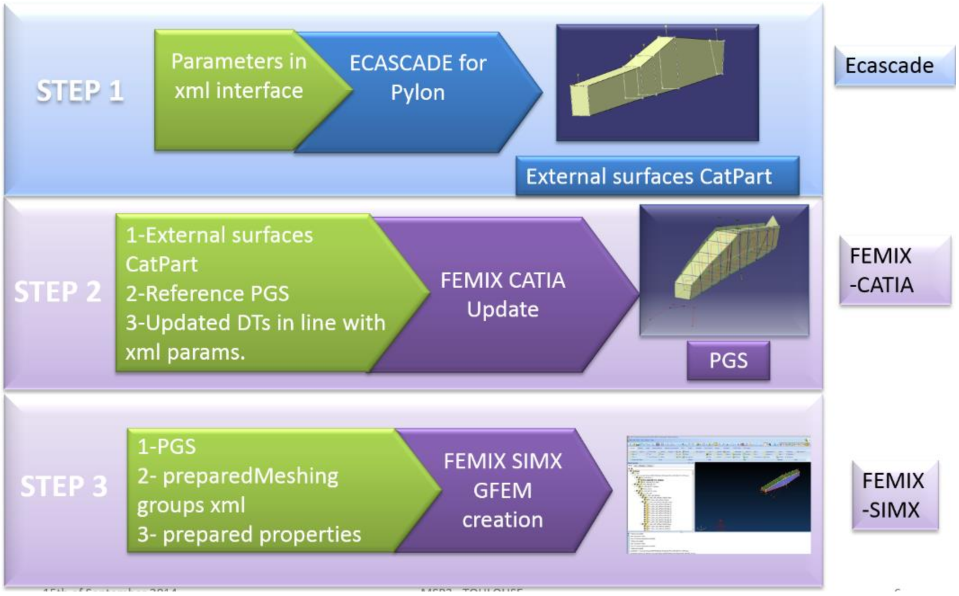

Figure 9: Airbus FEMIX based Flexible Model Generation

Multi-Level Coupling is managed then by an extension of FEMIX capabilities to the DPOs relevant to the various additional domains like thermal one (by the way FEMIX for non-purely structural solution has been demonstrated as well in CRESCENDO for Acoustics), and the optimization “block” is implemented by coupling a Nastran SOL200 Finite Element Model run to the Sizing process (second level of optimization) within Airbus Sizing legacy environment by the mean of Nastran DRESP3.

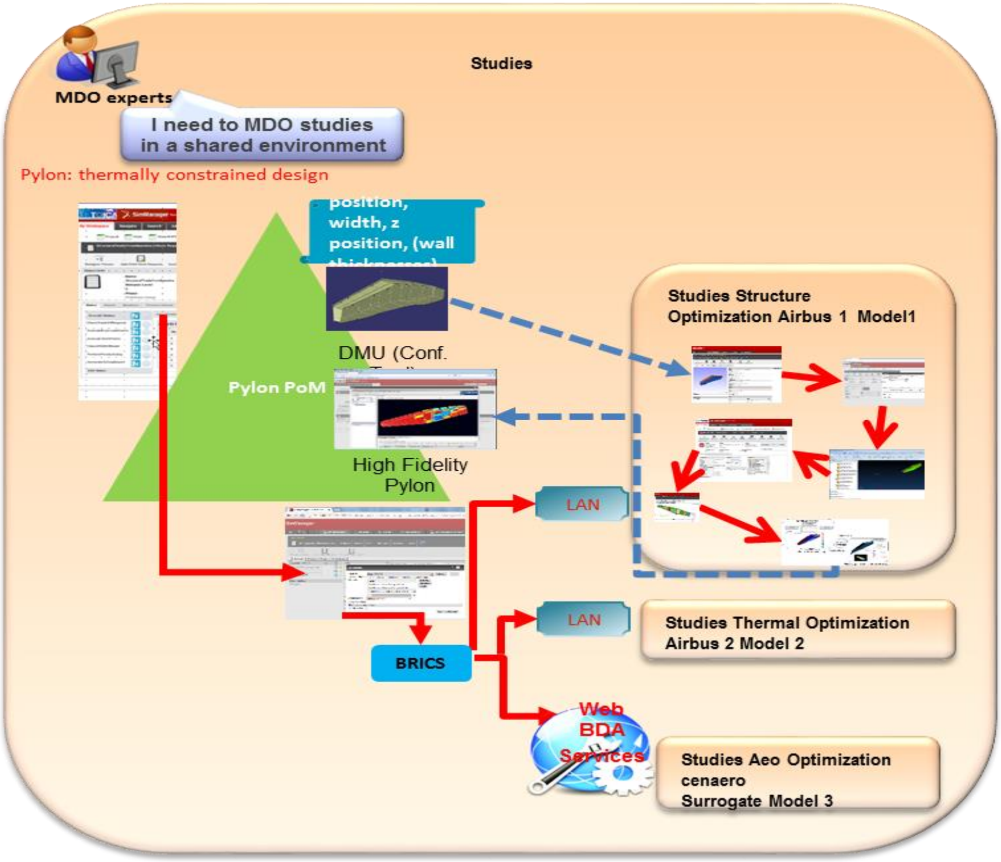

Figure 10: Multi-Level Multi-Disciplinary process

Along the 5th plateau (MSP5) execution, SimManager took into account the collaborative MDO distribution of surrogate models for the structural, thermal and aero domains in one hand, while it was driving on the other hand, the structural optimization to sizing process. As illustrated in Figure10. This was achieved with support from NLR's tool named BRICS [6] and Cenaero's platform known as MINAMO. The flexible model capability from SimXpert has matured and will execute a full automatic coupling of the structural optimization process with thermal and aero surrogate models at horizon of 6th plateau.

In that scenario, the post processing with architects' cockpit and risk reduction associated to value assessment were also demonstrated for MSP5. (Figure 11)

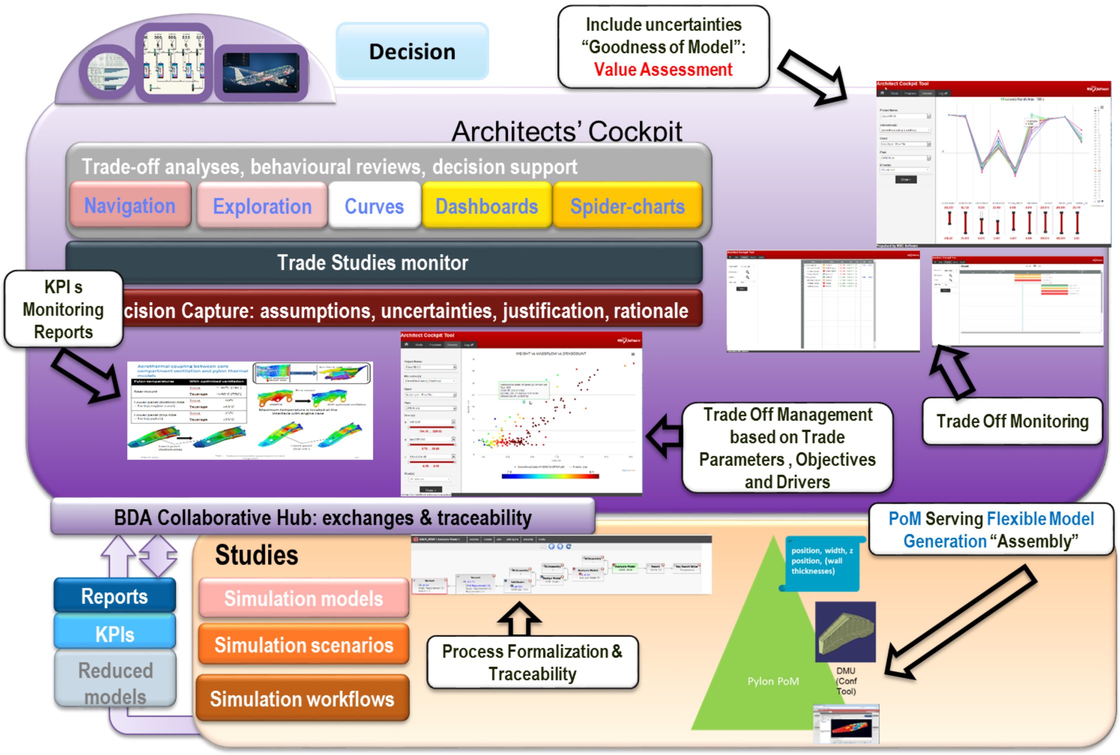

Figure 11: Trade-off decision and value assessment interaction

4 CONCLUSIONS

Through the review of one of the Airbus Use Cases, we have illustrated the relevance and benefit of TOICA capabilities, whether it relates to their interactions through MoSSEC as a standard for collaboration, or independently operating as M&S innovations.

A strong point has been made on the fact that TOICA capabilities, though split by project WBS to optimize consortium knowhow and resources, are not totally independent and conjointly contribute to TOICA high-level objectives.

In particular Flexible Model associated to Pyramid of Models and Coupling in the simulation world; as well as Super Integration from Architecture perspective is a Key enabler of Architects' Cockpit: a pillar of TOICA.

It is important to notice that between mid-term project presented in previous papers [9] and outcome of 5th plateau detailed in chapter 3, the solutions have matured to higher level of maturity. Indeed the referenced demonstration executed by end users themselves, within an IT infrastructure exact image of their industrial working environment, enabled validation of a

TLR4, for Architect's Cockpit and Flexible Model capabilities acting here in a tight interaction. This trend is expected to mature even more for the last plateau to be held just before this paper is publicly presented.

5 ACKNOWLEDGEMENT

The authors from Airbus and MSC thank their colleagues and partners involved in the use cases described, for their contribution to this work. Namely we were able to capitalize on NLR's technology for the distribution of MDO request, while Design of Experiment was conducted by Cenaero's framework.

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