

Minimizing Aircraft ECS Bleed Off-Take - Virtual Integrated Aircraft Applications

Deniz Unlu, Federico Cappuzzo, and Olivier Broca
Siemens Industry Software

Pierpaolo Borrelli
Finmeccanica

ABSTRACT

This paper presents the activities foreseen on the Leonardo Aircraft Division EIS (Entry In Service) 2020 derivative aircraft performed in the frame of the FP7 European research project TOICA (Thermal Overall Integrated Concept of Aircraft). On board air systems for conventional aircraft are fed by the bleed off-take which penalizes the amount of power available to the turbine of jet or turboprop engines. In order to minimize such operating penalties and optimize the energy efficiency of the overall aircraft, it is of major interest to support trade-offs at aircraft level including aircraft systems as early as possible in the development cycle. The study presents the Virtual Integrated Aircraft methodology and associated simulation activities relying on the system simulation platform LMS Imagine. Lab. This methodology is also relying on concept of flexible model and pyramid of models developed in the context of TOICA. Several aircraft configurations and ECS (Environmental Control System) packs architectures are studied and the different steps of the methodology are shown up to the trade between different aircraft configurations. From the very beginning of the design cycle, the requirements and the objectives for the air conditioning system are complemented with thermal requirements by performing thermal evaluations for the design points covering the aircraft operating conditions. Pre-sizing of every ECS pack component is achieved. Then, the resulting ECS packs numerical models are integrated with the engine bleed air system and the thermal model of the structure including the different heat loads, passengers and electronic equipment mainly. The integration is finally assessed over complete flight missions allowing to validate not only the steady state ECS performance, but also the transient pull up and pull down conditions as well as the overall engine bleed off-take and energy balance.

CITATION: Unlu, D., Cappuzzo, F., Broca, O., and Borrelli, P., "Minimizing Aircraft ECS Bleed Off-Take - Virtual Integrated Aircraft Applications," *SAE Int. J. Aerosp.* 9(1):2016, doi:10.4271/2016-01-2054.

INTRODUCTION

The present study shows the virtual integrated aircraft concept applied to study the environmental control systems integrated in the aircraft. It shows how the methodology can help and secure the development cycle of a complex product like an aircraft. First, the virtual integrated aircraft methodology is introduced. Then, the different phases of the models creation and validation required to perform the study are described: the thermal modeling of the structure of the aircraft fuselage, the pre-design of the ECS pack, the evaluation of functional models of both architectures studied and finally the results of the trade-off considering the transient pull-up and cool-down scenarios. Finally, conclusions and prospects are drawn.

VIRTUAL INTEGRATED AIRCRAFT METHODOLOGY

The TOICA [1] project relies on several aircraft configurations that are used as benchmarks in order to develop and evaluate the tools and methodologies necessary to execute thermal assessments of different aircraft architectures. In particular, the study described in this paper is based on the Leonardo Aircraft Division EIS 2020 derivative configuration, which is a high wing twin turboprop, conventional "T" tail, with tricycle undercarriage and main landing gears retractable into the fuselage.

A list of Top Level Aircraft Requirements (TLAR) was provided for this configuration with the intent of delimiting the perimeter, specifying the operating conditions and setting the goals for the trade-offs and optimizations to execute. The most compelling

requirements for the optimization described in the paper are expressed by the aircraft range with maximum passenger payload, the typical mission profile, the cruise speed, and the climb requirement. In fact, these requirements are directly linked to the power needed by the ECS to regulate temperature and pressure in the aircraft cabin and cargo. The TLAR are then decomposed and articulated for each system by the respective architects, resulting into the Design Requirements and Objectives (DRO). To give an example, the main functions identified for the air conditioning system (ATA 21) are: cabin and cargo temperature control, cabin pressure control, equipment cooling, moisture contaminant control. Requirements about the system performance, heating, cooling, distribution, ventilation, pressure and temperature control are given.

The purpose of the analysis is then to minimize the ECS bleed off-take, respecting the requirements and objectives received, with the means of simulations models. It is clear that such a complex task requires a considerable effort in creating the models, organizing the modeling process, coordinating its stakeholders, and managing the artifacts and data involved in these activities, especially in the context of the extended enterprise as it is the case for the TOICA project. For this reason, the authors decided to rely on a methodology capable of structuring and consolidating this process, referred to as the Virtual Integrated Aircraft (VIA) methodology [2].

The VIA is defined as a set of methods that enables the virtual integration of complex systems since the early stages of the aircraft design process. The methodology is particularly effective when relying on a software platform capable of:

1. Performing multi-domain, multi-level simulation
2. Integrating simulation models created with different tools
3. Version models and data
4. Organizing the workflow by assigning roles with different rights on the extended enterprise repository to the process stakeholders (role based access control)
5. Providing architectures reconfigurations capabilities

The modeling process proposed by the methodology, and applied in this analysis, is schematized in [Figure 1](#).

The first step consists in defining the analysis to execute, stating the expected outcome of the modeling activities, the aircraft systems involved, and providing the necessary boundary conditions. In this project, the purpose of the analysis is to minimize the bleed off-take of the ECS on the aircraft engines compressor stages. The systems identified are the air conditioning (ATA 21), the pneumatic (ATA 36) system and the structure considered from a thermal standpoint.

The main operating conditions are specified in [Table 1](#), for ground and cruise conditions three standard days are considered: cold, hot and extra hot. For each of them, conservative assumptions regarding heat loads and humidity are made. The expected outcome of the analysis is to validate the steady state ECS performance, the transient pull up and cool down scenarios as well as the overall engine bleed off-take and energy balance.

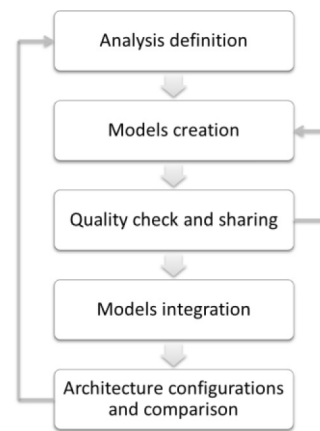


Figure 1. modeling process and simulation

Table 1. operating conditions

	Ground conditions			Cruise conditions		
Day	Cold	Hot	Extra Hot	Cold	Hot	Extra Hot
Δ ISA	-35	25	35	-35	25	35
Mach	0	0	0	0.4	0.4	0.4
Altitude [ft]	0	0	0	25000	25000	25000
Heat loads [%]	20	100	100	20	100	100
Humidity [g/kg]	0	30	30	0	4	4

The second phase of the methodology applied to this study regards the numerical models creation, activity performed with the software LMS Amesim. The first step consists in specifying how the different models to be integrated will communicate with each other. This is achieved establishing their Interface Contract Definition (ICD) based on the systems functional analysis and upon the agreement of the systems architects involved in the modeling activities. The main goal of this step is to eliminate compatibility issues during the integration phase and provide the means to assess different kind of analysis keeping the same model organization. For instance, the ICD selected for the air conditioning system accounts for an exchange with the pneumatic system, the structure, deemed as thermal conductor, and the aircraft volume of air into which the cabin, cockpit and cargo are discretized. Within LMS Amesim, the ICD takes the form of a supercomponent, as depicted in [Figure 2](#), where each port enables an information exchange representing physical quantities with other systems. In particular, air pressure is imposed by the pneumatic system depending on the amount of mass and enthalpy flow rate consumed which are processed by the system and directed to the aircraft zones to control their temperature and pressures.

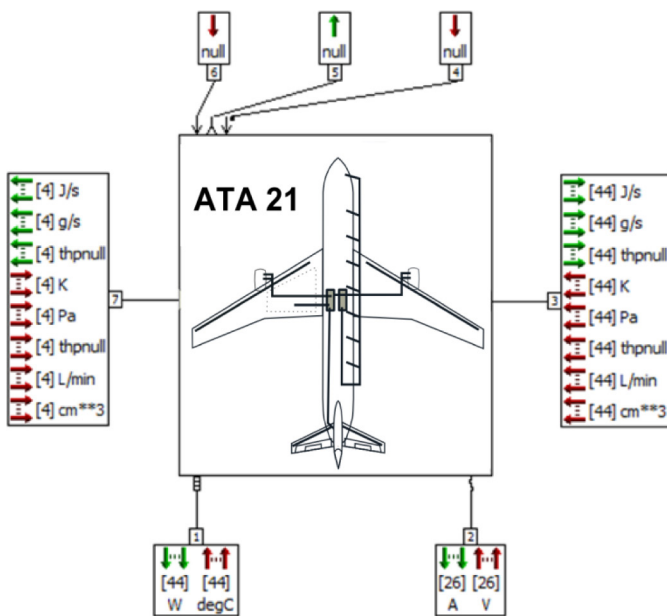


Figure 2. interface contract definition for the air conditioning system

Once models are created, the quality control and sharing phase takes place, supported by version control software with role based access control capabilities, as LMS Sysdm. The software establishes a connection among a common data repository, where models and data are stored, and local machines, where models and data are created and/or consumed. Once shared, the relevant actors of the modeling process can make a local copy of the model they need in order to integrate them with their current tasks. However, in order to coordinate this process and secure the contribution of every actor, a lean hierarchy is established by using rights allocated to the users. Roles and the associated rights are particularly convenient to manage intellectual properties and confidential data attached to the models, as the access to the information stored in the common repository is regulated through them.

The actors identified in this study are based on the TOICA workflow, and a dedicated set of roles were associated to them to organize their interactions. For instance, simulation engineers of the extended enterprise can read and publish models only in a given locations of the repository (called classification nodes) structured depending on the system they are responsible for, or the team they work with (functional and/or organizational classification). At the same time, they are not authorized to access to other locations, avoiding any unwanted interactions with simulation activities from other teams. Senior engineers have the roles and rights to read the models published in the repository's classifications that constitute their perimeter of expertise. They have the particular right to validate the models and data associated, action that is consequent to a quality check with respect to experimental data available and the specifications issued from the analysis definition phase, making them available to a larger audience. Clearly, if models' quality is not considered sufficient, they must be improved before being shared with the modeling process stakeholders. The aircraft and systems architects are the final consumers of the modeling and simulation

activities, and for this reason their role is limited to the mere reading of the validated models and simulation results that they can consult to support their decision.

Versioning control is performed with a tree like approach relying on branches and trunk notions, schematized in Figure 3: every time a new file collection is published to the repository, a trunk and a branch node are initiated. More than one branch can exist at the same time, enabling parallel work on different versions of the same model for instance. However, only one branch node can be validated, i.e. merged into the trunk, by validating it. Thanks to this approach, it is possible to trace the evolution of the modeling activity and retrieve at any time previous versions reducing risks related to loss of data or work.

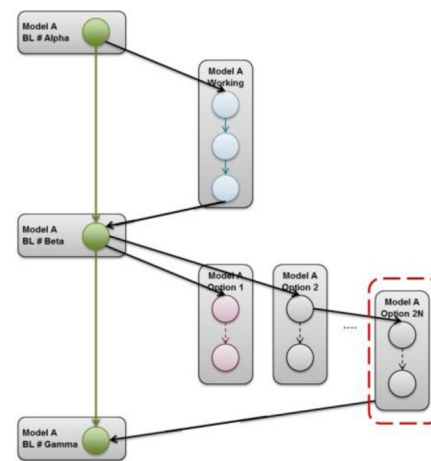


Figure 3. visualization of a simple versioning process

At this point, the models of the pneumatic system, the air conditioning system and the structure are completed and validated against the analysis requirements. The next step of the methodology consisted in their integration, activity that was eased by the compatibility of the models interfaces as all the connections among models had been declared and identified a priori.

Finally, by integrating different variants of the air conditioning system, respectively 3-wheel and 4-wheel air cycle machines, it was possible to assemble two architectures and perform a trade-off as explained in the next sections. This task is usually executed by the system architect, who is in charge to select the best configuration, relying on his expertise and supported by simulations results.

However, they do not necessarily have enough expertise on the modeling techniques, or simply the time, necessary to create the assemblies and analyze them. For this reason, a system architecture management tool, such as LMS SystemSynthesis, is needed to capitalize all the previous phases of the modeling process, providing continuity between the engineers working on the models development and the architect that relies on them to support important decisions concerning the system design. The outcome of the analysis can then be used to refine the analysis request, and the process starts again from the first phase, taking advantage of the artefacts and expertise developed in the first iteration.

AIRCRAFT STRUCTURE THERMAL MODEL

The models creation phase relies on the outputs of the analysis definition phase. The intent being the minimization of the bleed off-take, the first part of the study aimed to model the thermal behavior of the aircraft fuselage structure. The goal of this model is to evaluate the global conductance of the structure and to assess the ECS power requirements on the overall flight envelope. For this purpose, a thermal nodal model of the aircraft fuselage was developed based on the lumped parameters method, similarly to the approach described in [10]. The primary structure was discretized into frames along the aircraft longitudinal axis, each of them modeling the following heat transfers:

- Convection between the outer skin and the outside air
- Radiation between the outer skin and the external environment
- Direct solar radiation through the windows
- Conduction through the structural part
- Convection between the internal surfaces and air volumes
- Heat exchanges with internal loads (passengers, galleys and electrical/electronic equipment)

This lumped modeling approach for the thermal structure enables to evaluate the heat transfer in the longitudinal and radial direction of each frame, and to compute the temperature of the primary and secondary structures element such as skin, insulation blanket, liner, floor, stanchion and horizontal beam, represented by thermal nodes. It is interesting to notice that thanks to the longitudinal discretization and the availability of these frames stored as supercomponents in a dedicated library, it is possible to reuse them to quickly estimate the impact of geometrical variations along the longitudinal axis. Furthermore, by respecting the ICD of the systems involved, one can vary the level of detail or modify the models' content, without disrupting the integration phase that takes place further down in the process.

The frame item super-component and its content are depicted on the upper part of Figure 4. It includes two sections of the aircraft fuselage structure modeled by adopting the one-dimensional heat transfer hypothesis. The thermal nodes considered for the two sections are depicted on the bottom part of the Figure 4. Besides, heat transfers are managed both in radial and longitudinal directions.

In addition to structural thermal nodes, zonal or air volume nodes are considered as follows:

- One node for the cockpit
- Two nodes for the cabin, forward and aft
- One node for the electrical bay
- Two nodes for the cargo, forward and aft

Each zonal thermal node is connected to several frame item super-components. Zonal nodes' temperatures can be imposed or computed depending on the simulation intent. To compute air conditioning unit (ACU; also called ECS pack) system requirements, targeted temperatures are imposed, while to validate the integration of the air conditioning unit and therefore its transient behavior, these

temperatures are computed and can be monitored as well. Ambient conditions are computed thanks to the aircraft altitude and speed, and based on the International Standard Atmosphere (ISA) with a delta ISA (ΔISA) consideration to mimic cold, hot or extra hot day conditions.

Direct solar radiation is modeled as a heat flux source applied both to the skin and to the windows. This heat flux is supposed to be fully absorbed by the aircraft skin. Direct solar radiation through transparent area is applied by using a coefficient of overall transmissivity.

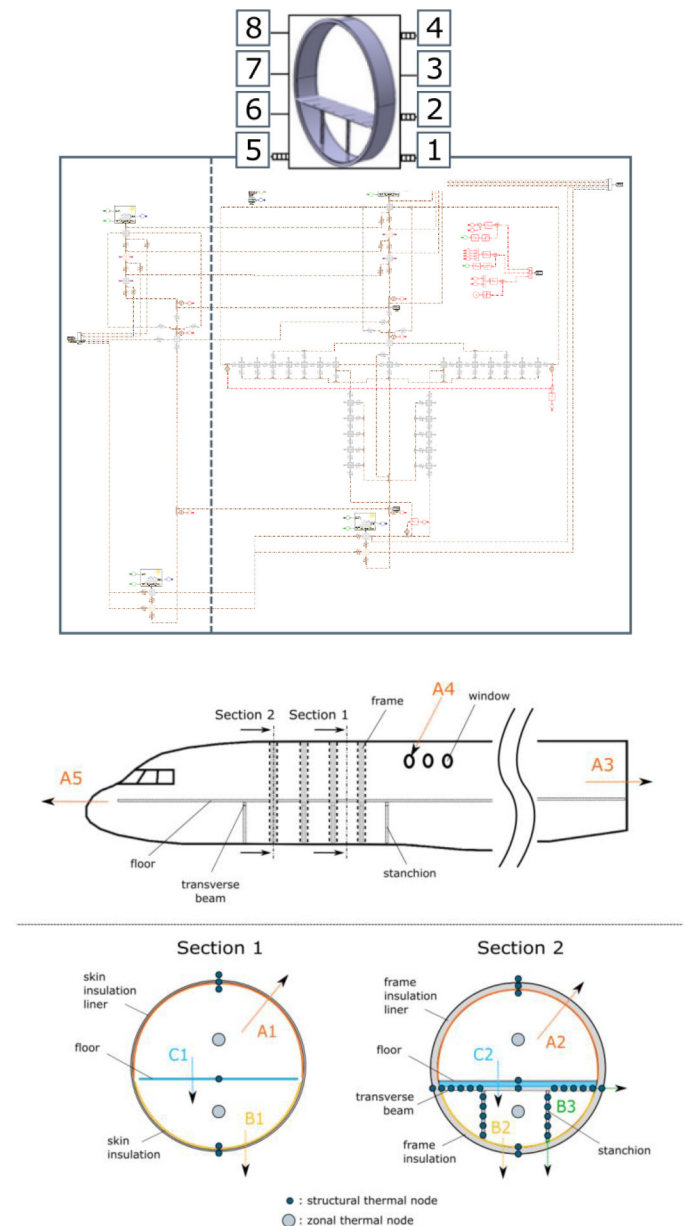


Figure 4. Frame super component with several ports on the left, {1, 2} cabin and cargo temperatures; {3} post processing vector; {4, 5} longitudinal heat exchanges; {6, 7, 8} external temperatures and airspeed; fuselage structure modeling nodal approach on the right hand side