INVESTIGATING SYSTEMS ARCHITECTURES AT THE AIRCRAFT LEVEL – TOWARDS A HOLISTIC FRAMEWORK FOR THE AIRCRAFT SYSTEMS DESIGN PROCESS

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Abstract

The paper introduces an integrated conceptual design environment for aircraft-level investigations of novel system architectures, which has been developed in the context of the European Clean Sky research initiative. The SysArc software provides the Green Regional Aircraft project with the enabling technology for validating and demonstrating the feasibility of bleedless architectures suitable to meet the pollution and noise reduction targets set for regional aircraft that will enter the market in the 2020s. The SysArc tool is based on a commercial software platform for knowledge-based engineering and conceptual aircraft design. The paper presents the tool architecture; key functionality and the supported work processes and discusses the integration of the SysArc software with tools for model-based systems engineering.

1. INTRODUCTION

With global air traffic expected to continue its growth over the next decades and the heightened relevance of ecological concerns, the aviation industry's greatest challenge is to mitigate its impact on the environment. Despite a steady stream of innovations in the aerospace industry, the natural rate of technological and operational improvements is not likely to compensate more than a fraction of the total increase of emissions.

If not addressed upfront, environmental impacts could prove to be the constraining factor for air transportation growth in the 21st century. A recent study of the economic effects of climate change predicts a 20% reduction of global GDP if stakeholders fail to act toward the short-term development of low carbon emission and high-efficiency technologies[1].

In order to accelerate the introduction of green technology and advance sustainability in aviation, the European Union has launched the Clean Sky Joint Technology Initiative, a massive transnational research program which addresses all key aspects of the air transport system.

The technological innovations developed under the Clean Sky initiative will significantly advance beyond the current state of the art and are expected to be available for industrial application within a seven-year timeframe. Research activities commenced in 2009 are anticipated to produce a series of flying technology demonstrators by 2014.

The Clean Sky research activities are organized in six divisions, or Integrated Technology Demonstrators (ITDs), which focus on different segments of the air transport system.

Clean Sky's Green Regional Aircraft ITD, see FIG 1, explores ways of improving the environmental performance of short-haul air transport, examining a wide range of contributing factors from composite aero structures to mission and trajectory management.

FIG 1. Artist's impression of the Green Regional Aircraft

Whereas the improvement of aircraft efficiency has traditionally relied on the classical domains of aerodynamics, structures and propulsion, the Green Regional Aircraft project strongly emphasizes systems architecture design as a key activity in preliminary aircraft development, in line with some authors who, in view of the rapid increase in the complexity and energy demand of aircraft subsystems go as far as contending that "success or failure in the Aerospace and Defense sector is determined by the approach taken in the development of systems and how well or otherwise the systems and their interactions are modeled, understood and optimized."[2]

The high interdependence of systems in today's aircraft means that systems cannot be analyzed in isolation, but must always be considered in the light of interaction with other systems, and as making a contribution to the performance of the aircraft as a whole. An efficient, holistic approach to systems design is particularly important in the development of regional aircraft because of the comparatively higher significance of the operating empty weight with regards to fuel consumption and emissions and the more restrictive volumetric packaging requirements.

In the frame of a Call for Proposal, PACE was tasked to supply the Green Regional Aircraft ITD with a software tool capable of modeling and evaluating conventional and unconventional systems architectures and assessing their impact at the overall aircraft level.

The software was initially to be applied to demonstrate the feasibility of systems architectures that do not rely on bleed air off-take, i.e. to evaluate the potential for replacing the less energy-efficient pneumatically or hydraulically driven systems with electric alternatives. The aircraft functions contributing most significantly to the overall power demand, and hence engine power extraction, are electrical power generation and distribution, power electronics, electrical engine starting, cooling, heating and compression (ECS, ice protection and equipment cooling), and electro-mechanical actuation (landing gear system, flight controls).

In view of the wide range of subsystems to be considered, the most salient feature of a supporting software tool must be the ability to integrate all of these in a consistent environment which gives a true representation of the interactions between individual subsystems and the overall system architecture.

The subsequently developed Systems Architecture Design (SysArc) solution builds on a mature, commercially available conceptual aircraft design tool, which allows capturing diverse geometric-physical and non-physical design aspects in a single data model. The functional extensions developed in the course of the project are geared toward a further detailing of the preliminary aircraft model, which allows the modeling, analysis and sizing of systems architectures in the context of the overall vehicle. This holistic approach eliminates the risk of design inconsistencies or unforeseen behavior in the integration phase and ensures a reliable prediction of their impact on the aircraft's key parameters early in the design process.

2. SYSARC SOLUTION DESCRIPTION

2.1. Software architecture

The SysArc solution was built on the knowledge-based engineering design platform Pacelab Suite and its conceptual aircraft design module APD. In combination, these modules provide a fully-fledged aircraft design environment in which to conduct systems architecture investigations. To this, an additional functional layer was added to provide systems-specific functionality.

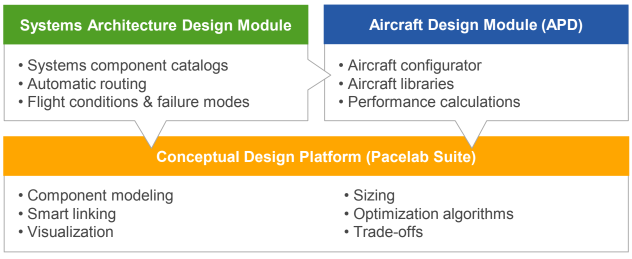


FIG 2. Software modules of the SysArc solution

The Pacelab Suite platform supplies the basic functional and procedural infrastructure for early-stage product design such as the ability to parametrically model, analyze and size complex technical systems. Pacelab Suite uses a consistent, object-oriented knowledge modeling approach which (a) clusters parameters and methods in generic, reusable building blocks (Knowledge Components) and (b) supports their assembly into complex systems with an innovative technology called Smart Linking. Smart Linking is a generic mechanism for automatically aggregating information in dynamically defined systems. The underlying mechanism browses the data model for parameters with specific, user-definable properties. Smart formulas are template-like expressions that allow generic description of computations and that create instances of their template expressions upon detecting a matching condition. In combination, these features allow the adoption of an interactive, generative approach when building highly complex parametric product models.

The exploration of the resulting model, whether performed manually by the user or through the application of numeric sampling or optimization techniques, is controlled by Pacelab Suite's solving engine, or Resolution System. The Resolution System automatically analyzes the non-linear equation system underlying the parametric model, the methods linking the parameters and the calculation direction (i.e. which parameters are input, which are output). The analysis results in the automatic identification of a solving sequence which satisfies all relations. The solving sequence typically involves complex cyclic dependencies which require iterative, numeric solving; it is applied automatically every time a parametric value is modified.

The solving engine's inherent knowledge of the mathematical system's topology is unique to Pacelab Suite and has two important advantages in addition to its ability to automatically solve user-specified models. Firstly, it allows an incremental or partial update of the system, which significantly improves the runtime performance of the application. This is crucial when dealing with large-scale models that would otherwise exhaust the computing resources typically available at an engineer's workstation. Secondly, it enables users to flexibly swap the input or output status of parameters, i.e. to enter a target value and calculate the required inputs instead of manually tweaking input values to arrive at a given result. Consequently, the versatility of the product model is greatly increased, because it can be configured to a specific view of the engineering problem without the need to rebuild it from scratch.

Pacelab Suite also provides an extensible set of robust algorithms for smooth, non-smooth and global optimizations as well as multi-parameter sampling of the design space to support trade-off investigations.

To this, the aircraft design module APD provides an additional functional layer that supports the specific tasks of aircraft conceptual design. The APD module adds domain-specific Knowledge Libraries which provide the basic building blocks for all major tasks involved in commercial aircraft modeling, analysis and sizing. APD Knowledge Libraries comprise of geometric aircraft components such as lifting surfaces, fuselage or engine models, mass and aerodynamic estimation modules, and a comprehensive performance calculation kernel to analyze design and off-design missions. Task-specific graphical user interfaces allow a quick and interactive definition of the baseline aircraft through the installation and positioning of predefined components such as wings, tail surfaces, engines or undercarriages. Alternatively, calibrated models of existing corporate and commercial aircraft are available from the resident aircraft library. The graphical layout of the system is illustrated in FIG 3 below.

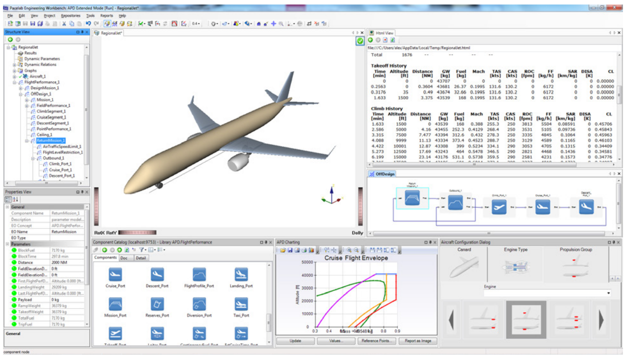


FIG 3. Graphical view of Pacelab Suite and APD module

APD also provides a standard set of analysis methods for weight, high-speed and low-speed aerodynamics, flight performance and mission analysis, and static stability which can be flexibly replaced with proprietary and higher fidelity methods. Aircraft properties can be viewed and exported as statistical reports and graphical charts, as illustrated in FIG 4.

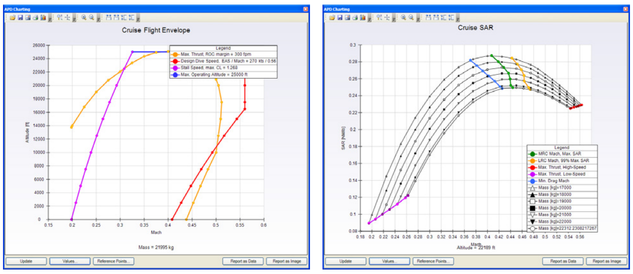


FIG 4. Typical performance charts generated with APD

The main development effort for the Green Regional Aircraft ITD was devoted to implementing and integrating the following systems-specific capabilities:

- Creation of a system component catalog for all systems under investigation, with specific emphasis on power demand. System libraries considered in this first development phase included electric power generation, power conversion and distribution, fuel system, environmental control system, electro-mechanical actuation systems such as flight controls and landing gear, as well as electrical loads.
- Graphical-schematic build-up of architectures using above system component catalogs
- Definition of physical installation areas (i.e. compartments) to control the geometric position of system components and to analyze their thermal impact
- Automatic transfer of logical system connections into the physical space of the aircraft, providing their physical properties such as length or mass as well as the associated power losses (electric voltage or hydraulic pressure). This was accomplished by automatically routing the specific power distribution elements, e.g. cables, pipes or ducts.
- Load analysis and load management as a function of flight phase and/or system failure modes
- Coupling of the systems architecture module with the underlying aircraft design system by feeding system mass estimations and power off-take requirements to the aircraft design module for instant assessment of their impact on key performance parameters (e.g. climb capability or fuel consumption)

These capabilities and their associated workflows are described in detail in the sections below.

2.2. Key capabilities

2.2.1. Basic workflow

FIG 5 below outlines the basic workflow for a holistic investigation of aircraft systems architectures. The SysArc solution covers all process stages, but additional tools, methods, models etc. can be plugged in if and when required. Moreover, the application does not impose a particular workflow on the user but flexibly adapts to team-specific task distributions.

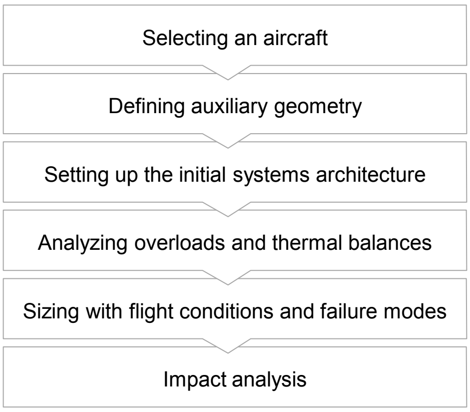


FIG 5. Overview of the SysArc workflow

2.2.2. Selection and sizing of baseline aircraft

The quickest way of setting up an aircraft configuration is to derive it from an aircraft model retrieved from the resident library. For the Green Regional Aircraft ITD, the library was extended with dedicated models for turboprop and jet engine aircraft with 90-130 seats and a range up to 3000 NM. Due to their full parameterization, these aircraft models can be easily modified by adjusting high-level design parameters such as number of passengers, engine types, engine installation, wing configuration, fuselage shape, etc. FIG 6 illustrates the definition of the overall aircraft configuration.

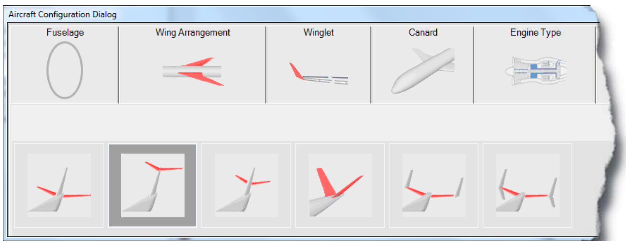
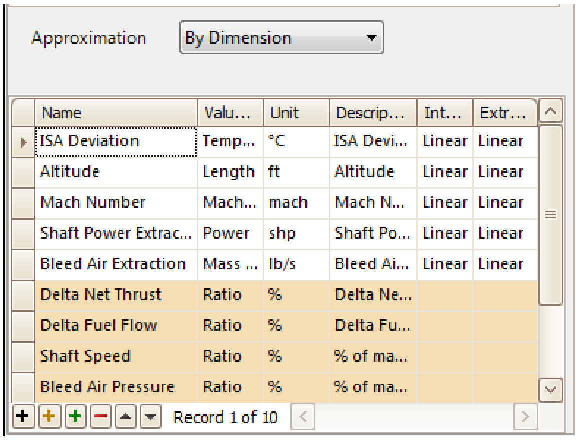


FIG 6. Definition of overall aircraft configuration

After values have been assigned to key geometry parameters such as wing area, aspect ratios, and general aircraft dimensions, the SysArc solution calculates the mass and aerodynamic properties of the current aircraft configuration. With pre-defined calculation scenarios, that is, sets of parameter input/output settings, the system can be calibrated to meet known results or to account for technology factors, for example.

Mission and airfield performance are calculated from the aircraft's aerodynamic and engine properties based on user-specified design missions. Subsequently, parameters and calibration factors can be iterated and fine-tuned until they meet the targeted objectives. This is supported by trade studies and built-in optimization algorithms, which automate the exploration of the design space.

The systems architecture design module extends the propulsion system characteristics provided by the APD module to supply engine data such as delta fuel flow or thrust as a function of shaft power or bleed air extraction, in addition to the standard thrust and fuel flow data required for mission analysis.



Name	Valu...	Unit	Descrip...	Int...	Extr...
ISA Deviation	Temp...	°C	ISA Devi...	Linear	Linear
Altitude	Length	ft	Altitude	Linear	Linear
Mach Number	Mach...	mach	Mach N...	Linear	Linear
Shaft Power Extrac...	Power	shp	Shaft Po...	Linear	Linear
Bleed Air Extraction	Mass ...	lb/s	Bleed Ai...	Linear	Linear
Delta Net Thrust	Ratio	%	Delta Ne...		
Delta Fuel Flow	Ratio	%	Delta Fu...		
Shaft Speed	Ratio	%	% of ma...		
Bleed Air Pressure	Ratio	%	% of ma...		

FIG 7. Data table providing engine characteristics

Engine data are hosted within a standard parameter type for multi-dimensional data tables provided by the underlying Pacelab Suite platform. The tables (see FIG 7) are unlimited with regards to data records and their dimensions, and provide built-in, user-specifiable interpolation methods. Data can be quickly imported from spreadsheets or exported for further processing. For the purpose of the present study, the additionally required engine data was imported in a normalized form from a representative, generic engine deck.

2.2.3. Definition of auxiliary geometry

In order to facilitate the layout of systems architectures, the aircraft model created with APD is equipped with auxiliary geometries, a generic compartment model which allows the segmentation of internal volumes; and a pathway model that specifies default routes for connections such as cables, ducts, or pipes.

The additional geometry facilitates the installation of systems components, provides numeric input for thermal analysis and enables the automatic routing of electric and hydraulic connections.

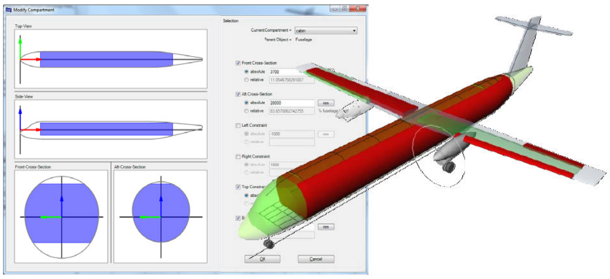


FIG 8. Compartment definition GUI and 3D model

Compartments can be defined in all major geometric aircraft components including fuselage, wing, horizontal and vertical tail or engine nacelles. The user interface provides visual aids to support the shaping and positioning of the compartment within the aircraft. The shape can be defined flexibly and permits the definition of cabin compartments and cargo holds, non-symmetric avionic bays, or wing box and leading and trailing edge volumes, see FIG 8. Once the compartments are in place, they provide comprehensive geometric data, including volumes and adjacent surfaces, which can be directly linked to internal thermal analysis models or external analysis tools. In addition, the aircraft geometry can be furnished with pathways, which specify permissible connection routes between components and are therefore prerequisite to applying the automatic routing algorithm.

2.2.4. Setup of initial systems architecture

Reflecting Pacelab Suite's building-block approach to modeling, the basic procedure for setting up systems architectures mainly involves selecting the required systems components from the component catalog and graphically establishing their connections in a dedicated schematic view.

The component catalog provided by the SysArc solution contains generic models of system components. The initial deployment encompassed basic parametric component models covering systems from Flight Control (FCS) and Environmental Control Systems (ECS) to Electrical Power Generation and Fuel Systems. The models were either derived from public-domain sources or implementations of external models which had been supplied by the industrial partners of the Green Regional Aircraft ITD. External models are wrapped as "black boxes", and augmented with the Pacelab Suite's capability to reverse the input or output status of their parameters. The component catalog is fully extensible and more systems could be added as the project progressed. In addition, supplier data for systems components can be imported from spreadsheet or database programs for rapid build-up of supplier-specific component catalogs.

Systems components are described by both geometric-physical and non-physical parameters. Of the latter, those related to cost aspects are part of the main metrics in order to balance the level of technological innovation and ready market acceptance.

Each component is accompanied by an in-depth hypertext documentation detailing design intent, parameter descriptions and suggested usage to help systems engineers select the appropriate building blocks for their investigation, see FIG 9.

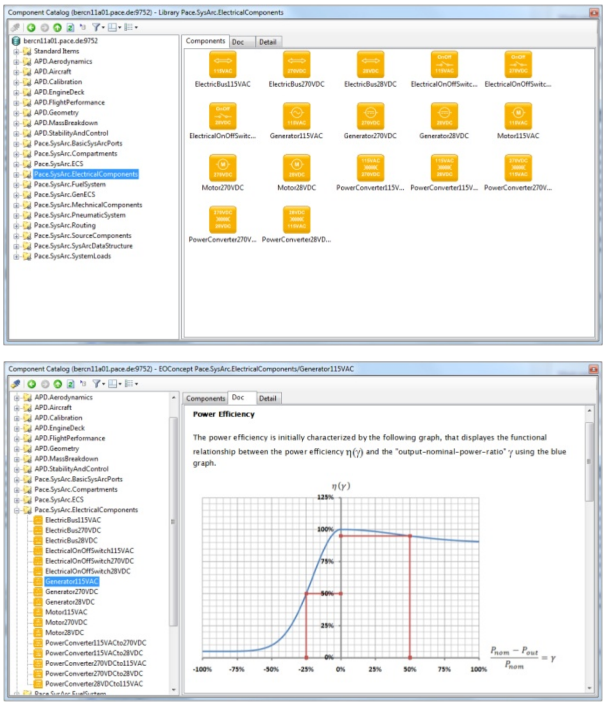


FIG 9. User interface of the systems component catalog

Part of the parametric description of system components are connector points, or Ports. Ports constitute a specific implementation of Pacelab Suite's Smart Linking technology and support the interactive build-up of architectures and configurations. Ports encompass a set of parameters that are characteristic for a particular domain (e.g. power and voltage for electric connections) and are managed by domain-specific rules, called Graph Formulas.

These rules automatically translate a connection that is established graphically by the user into complex mathematical relations. For example, when a line is drawn between the ports of two electrical components, the relevant rules create the required power summation formulas and will propagate voltages, thereby automatically taking into consideration the voltage drops induced by the ohmic resistance of the physical cable connection. Smart Linking is also applied for mass and center of gravity aggregation as well as for cost buildup. The graphical frontend presented to the user is task-specific (e.g. a schematics diagram for electrical wiring and another for the fuel systems) and guides the user by highlighting system components that may be connected to the selected port. See FIG 10 for sample schematic view of the overall power architecture.

The mathematical system resulting from the above procedure is highly non-linear, and cyclic. Although extensive experience had been gained before the project with Pacelab Suite's Resolution System and its capability to handle the numeric cycles as given in the conceptual design of aircraft, e.g. the mass performance loop, the extension and coupling of the model to system architectures posed an additional challenge that required specific attention. The ability to customize the solver for specific types of systems allowed coping with domain-specific numeric problems, and has resulted in a stable and robust solving characteristic.

When building the system architecture, the user has to specify primary and alternative power supplies for the loads, the latter of which will be used in case of major power sources failure. Through activation or de-activation of primary and alternative connections, the system can be analyzed for specific failure scenarios, which are described in more detail in the following section.

When the logical connections have been defined in the schematic view, the automatic routing of the physical system connections can be triggered. The routing algorithm seeks the shortest possible route between two system components along the previously defined pathways. The set of pathways to be used in the routing can be specified by the user in order to further steer the results. The software uses two algorithms to solve the single-source shortest path problem:

- Dijkstra's algorithm for electric connections, which determine wire length and dependent parameters such as mass or voltage drops.[3]
- the Steiner tree algorithm for fluid connections, where 1:n or n:1 connections need to be realized.[4]

The fidelity of the routing could be enhanced in the future in order to account for installation constraints such as engine blade, tire burst or volumetric limitations within a given pathway. However, for the purpose of estimating power losses and the mass of distribution elements at this state of the design, the present implementation offers sufficient precision.

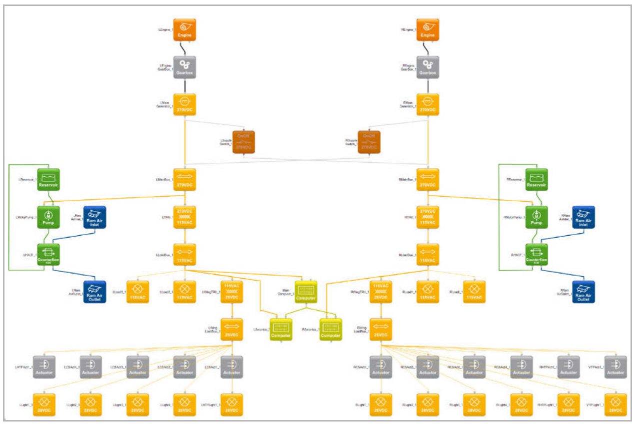


FIG 10. Schematic view of overall power architecture

The combination of logical systems architectures with the physical representation of system components and their connections in the 3D space of the aircraft constitutes a major strength of the SysArc tool as it delivers reliable estimates of the impact of a specific architecture that take into account both installation constraints and the aircraft configuration. In addition to gauging the effect of electric or fluid power losses along the system connections, heat losses are tracked by an integrated simplified thermal analysis model, which may be replaced by more sophisticated models where required.

In order to promote the reuse of validated systems architectures, the SysArc solution maintains a database for storing and retrieving complete architectures. Due to geometric variation, the application of pre-defined architectures to different aircraft types is challenging. The degree of automation for this feature has not yet been specified conclusively, but generic placement mechanisms ensure that system architectures can be exchanged freely between aircraft models.

2.2.5. Analyzing overloads and thermal impact

When the initial architecture is complete, it can be analyzed in terms of overloads and thermal balances. SysArc monitors main parameters such as power (electrical, mechanical, hydraulic), mass flow (pneumatic, fuel systems) or pressure required by subordinate components. The software automatically detects accumulated demands that exceed the capability of the provider and highlights the overloaded component in the layout.

The objective of the thermal management is to determine the volume, or mass flow, of the circulated air required to achieve a target ambient temperature. The ambient temperature can be defined individually for each compartment.

The required mass flow is basically calculated from the outlet temperature of the ECS component, the recirculation ratio of the mixing chamber and the target ambient temperature of the compartment. For illustration see also the schematic definition of the ECS system in FIG 11.

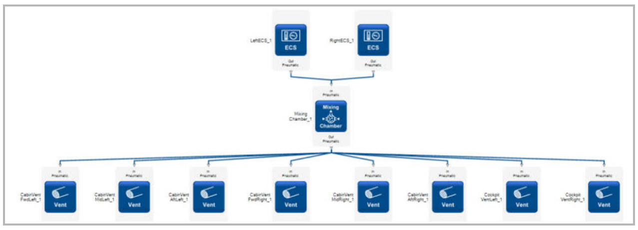


FIG 11. Schematic view of environmental control system

The compartments' demand of air cooling takes into account the heat emanating from passengers, crew and systems components and the performance parameter of the fresh-air vents. Additional pneumatic components like valves and fans can be added to fine-tune the flow model of the air stream.

2.2.6. Sizing for operational scenarios

Flight conditions and failure modes help to identify critical cases and limiting values and thus to establish the sizing conditions of a given systems architecture. Flight conditions account for systems components' changing operational states during the course of a flight mission (e.g. flap actuator in take-off vs. cruise phase) and allow calculating the power and cooling requirements of the aircraft systems under a specific set of conditions. Each flight condition is associated with a flight segment (e.g. take-off, climb or cruise) and described by (a) a set of environment parameters such as altitude, pressure, velocity or ISA deviation, and (b) the power consumption rate of all consumers at this point (expressed as a percentage of the nominal value). The required engine data is retrieved from the propulsion model. Applying a flight condition will automatically adjust the parameter values and trigger a recalculation of the mathematical system.

Failure modes, on the other hand, represent typical failure scenarios and are defined by a set of failed electric or hydraulic providers such as sources, generators, converters or distribution elements. Applying a failure mode to a systems architecture will result in a number of unsupplied consumers and prompt a switch to the alternative providers if previously defined in the architecture setup. FIG 12 displays the dialog for full-factorial sampling of flight conditions and failure modes.

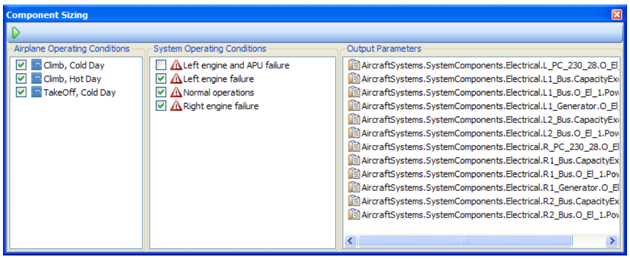


FIG 12. Flight conditions and failure modes

In order to ensure a reliable operation of the system under all conditions, systems sizing must assume a worst-case scenario, which may be difficult to establish for systems architectures lacking historic data. The SysArc solution supports the identification of critical cases and limiting values by analyzing full-factorial combinations of user-definable, typical flight phases and failure scenarios. Instances of both parameter sets can be defined within the application.

To enable the alternative providers to deal with the extra loads, SysArc allows switching the affected electrical loads to voltage-modulated operation. In modulated operation, a reduced voltage is supplied to subordinate systems, which restricts their power consumption to the working minimum and prevents an overload of the provider.

In order to determine the exact sizing conditions, the solving engine iterates over all possible combinations of flight conditions and failure modes, while monitoring key parameters such as power consumption, size and weight. The results are displayed in a ranked matrix so that the extremes can be identified. The flight condition with the highest power consumption can be used for the final sizing of the systems architecture.

The sizing results can be presented in an energy breakdown report, which allows aggregation of power consumptions or heat loads according to different, customizable criteria such as compartment or bus association, see FIG 13.

Pacelab SysArc - Energy Breakdown

B737-NG-Pace

Flight Condition: none

125000 lb, 15000 ft, Cruise, 0.8 mach, Cold Day

Failure Mode: none

Energy Sources Total of 2	Shaft Power [shp]	Bleed Air [kg/s]
Sum	31.37	0.00
Arithmetic Mean	15.68	0.00
Standard Deviation	0.04	0.00
LEngine_1	15.66	0.00
REngine_1	15.71	0.00

Compartments Total of 7	Total Heat Load [kW]	Electrical Heat Load [kW]	Secondary Heat Load [kW]
Sum	13.73	9.14	4.59
[+] Arithmetic Mean	1.96	1.31	0.66
Standard Deviation	2.91	2.63	1.13
[+] Cockpit_1	4.78	1.56	3.23
[+] FwdUnderfloor_1	0.67	0.45	0.23
[+] LInnerTank_1	0.23	0.00	0.23
[+] LOuterTank_1	0.23	0.00	0.23
[+] MainUnderfloor_1	7.36	7.13	0.23
[+] RInnerTank_1	0.23	0.00	0.23
[+] ROuterTank_1	0.23	0.00	0.23

FIG 13. Energy breakdown report

2.2.7. Impact analysis

In addition to providing the geometric host platform for the systems architecture design module, the APD module is used to assess the impact of the chosen architecture on the overall aircraft characteristics and performance. The two most important intersections between the system architecture module and APD in this respect are the mass chapter and the propulsion module. The integrated graphical user interface of both systems is illustrated in FIG 14.

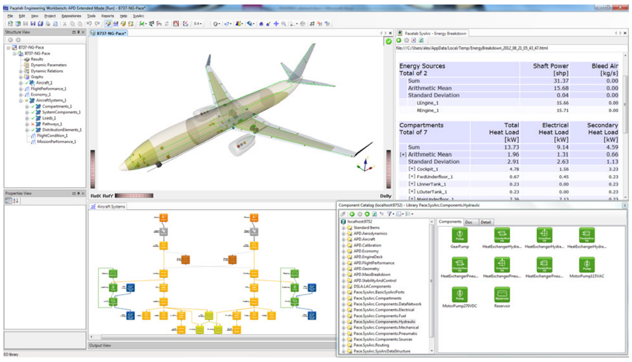


FIG 14. APD and SysArc under a single user interface

The total systems architecture mass, i.e. the summed masses of individual system components and their connections, is mathematically linked to the APD module's respective mass chapter entry (e.g. electrical systems mass, hydraulic systems mass). Consequently, every modification of the systems architecture is propagated to the aircraft mass chapter and can, if so wished, automatically trigger a recalculation of the overall mass chapter (including centers of gravity), the performance and all other areas affected.

At the same time, the propulsion module considers power off-takes as a function of the flight phase, assuming normal operations of all systems. The remaining engine power is then used for propulsion of the aircraft. Hence, modifications of the architecture may lead to modified performance capability (e.g. reduced or increased ceilings) or simply to lower or higher fuel consumption.

Through the integration with the APD module, the user is enabled to study complex questions very efficiently, while focusing on the principle task of designing systems architectures. The functionality provided by the SysArc tool can be applied to a range of use cases, from the design of new aircraft (which is the primary purpose in the scope of the Green Regional Aircraft project) to the modification of specific aspects of existing systems architectures.

3. INTEGRATION INTO THE ENGINEERING DESIGN PROCESS

Since the development for the Clean Sky project was concluded, the SysArc software has been introduced into the design processes of major aircraft and engine manufacturers and is being evaluated by 1st tier system suppliers aiming to offer integrated architecture solutions to their customers.

Introduction of the software into an industrial environment has highlighted the need for improved integration into the engineering design process. Through the underlying platform Pacelab Suite, the SysArc software offers a wide range of ready-to-use interfaces for integration into enterprise data management systems and allows comfortable integration with external codes and models; a further link of the SysArc solution with upstream design stages was identified as a future key requirement.

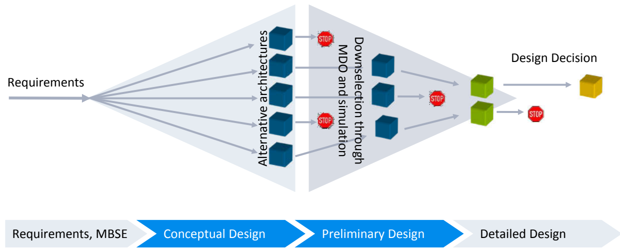


FIG 15. Engineering design process

FIG 15 illustrates an idealized process of complex systems design, where during the conceptual and preliminary design phases multiple competing architectures are modeled and evaluated through several stages with increasing depth of analysis. Two major obstacles impede the application of this paradigm and discourage exploration of new architectural alternatives:

- Generating computational models for each architectural alternative may prove to be too labor-intensive and hence costly.
- Keeping track of high and low level requirements when generating multiple competing architectures is difficult, increasing the risk of missing key design targets.

Whereas the SysArc solution addresses the first point through its interactive, assisted model-building capability, no functionality is provided to link design requirements with technical functions and their implementation into architectural elements.

Formal, model-based systems engineering (MBSE) methodologies, on the other hand, can provide excellent traceability of requirements throughout their transformation into technical functions and subsequent mapping to future hard- and software components, but fall short of adequately modeling the highly non-linear reality of complex systems through appropriate algorithmic support and may hence lead to ill-based architectural design decisions. Further, application of MBSE methodologies has suffered from poor penetration in the engineering community, mainly because of the complexity to model contemporary systems with the existing commercial software tools.

The situation described above prompted the IBM Research Lab in Haifa, Israel, and PACE to collaborate on the integration of an innovative IBM design environment for architectural optimization[5] with the SysArc software.

The IBM solution introduces a concept called “concise modeling”, that allows the definition of system architectures using an extended SysML language set, where the architectures are described through their composition rules in a generic fashion. This input is subsequently processed by a system for linear-constrained optimization and automatically generates architectural design alternatives. The architecture design environment is based on off-the-shelf products used for MBSE and is integrated with software products for requirements management.

The joint prototypical solution, called “Systems Optimization Workbench”, offers process improvements on both sides. From the perspective of the IBM design environment, integration with SysArc improved the methodology two-fold (see also FIG 16):

- By reading model data from the SysArc systems component catalog (see 2.2.4), the generation of candidate architectures is based on a single source of data that is later used in more detailed design stages, instead of using inconsistent component data bases.
- Automatic export and transfer of candidate architectures into the SysArc software allows fast evaluation of the alternatives in the “real-world” non-linear modeling and analysis environment.

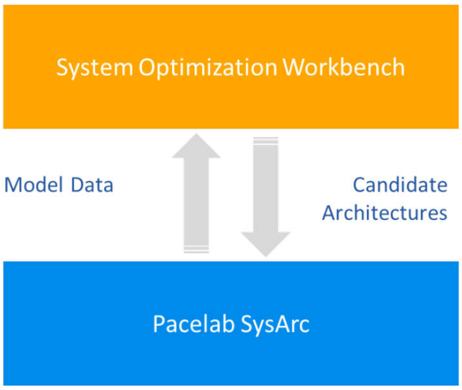


FIG 16. Engineering design process

From the SysArc perspective, on the other hand, the integration with the IBM design environment offers the following advantages:

- Initial definition of candidate architectures is further accelerated through the import of automatically generated, optimized architectures.
- Traceability of requirements can be achieved through linking SysArc with upstream software for requirements management.

Last but not least, the integration of both solutions can lead to better process integration between engineering departments by linking systems engineering design principles with multi-disciplinary design methodologies.

The prototypical solution was validated in collaboration with an industrial partner, who contributed a relevant systems architecture problem and the required data.

4. CONCLUSION AND OUTLOOK

The SysArc solution represents a novel technical approach to aircraft-level design and analysis of aircraft system architectures, which unites the logical definition of systems architectures with the physical layout of system components and their connections in the aircraft geometry. The software draws on the strength of object-oriented programming and knowledge-based engineering techniques to speed up modeling and analysis. The tight, yet runtime-efficient integration of systems architecture configuration within the conceptual aircraft model allows an instantaneous investigation of the impact of system architecture modifications on the aircraft characteristics and overall performance.

Thus, the software provides a comprehensive platform for the holistic investigation of modern, more-electric architectures which helps avoid errors that are the result of overlooking possibly penalizing side-effects of the new technologies applied. The software’s functional scope as defined by the Green Regional Aircraft project’s requirements has allowed quick adoption of the system by industry and offers a scalable platform to meet additional requirements, such as the inclusion of avionics systems into the architectural definition, or the application of the methodology to other types of aircraft, such as unmanned vehicles.

Future work emphasizes the integration with upstream and downstream engineering processes; to this end, the potential for industrialization of the joint work with IBM will be assessed, with special focus on the link of SysArc with software tools for requirements management.

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