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Application of a distributed MDAO framework to the design of a short- to medium-range aircraft

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Abstract

Advanced aircraft pre-design methodologies tend to involve an increasing amount of disciplines in a concurrent way. Previous research has advanced the capabilities of interlinking design tools and creating automated, multidisciplinary analysis and design workflows. A central challenge herein is found in the practical management of disciplinary knowledge. The main question that arises is: how to effectively set up the collaboration among engineers with different specialisations in order to operate the networked tools competently? In this context this paper presents an engineering framework enabling multidisciplinary analysis and optimisation and its application to the advanced pre-design of a short- to medium-ranged aircraft configuration. A system-of-systems approach is established by combining aircraft pre-design with system layout considerations, enforcing knowledge exchange between experts with different backgrounds. Still existing technical, as well as non-technical collaboration barriers are identified and described. It is concluded that although showing large potential for attaining improved design results, larger focus on organising effective collaboration among engineers is required to advance the multidisciplinary design approach to an even higher level.

Keywords: multidisciplinary design analysis and optimisation, collaborative aircraft design, system-of-systems approach, distributed analysis frameworks

NOMENCLATURE

CPACS	Common Parametric Aircraft Configuration Scheme
IDL	Integrated Design Lab
MDAO	Multidisciplinary Design, Analysis and Optimisation
ParADISE	Parametric Architecture Designer for Integrated Systems Engineering
PrEMISE	Pragmatic Engineering Model for Integrated Systems Engineering
RCE	Remote Component Environment
TLAR	Top Level Aircraft Requirements

1 INTRODUCTION

As stated by the AIAA technical committee, the amount of disciplines involved in aerospace design has been increasing steadily [1]. To identify and exploit the large amount of interdisciplinary dependencies, integrated design approaches are finding their application already in early design stages. The Multidisciplinary Design, Analysis and Optimisation (MDAO) methodology is seen as one of the most promising integrated approaches, as described by [2], [3]. Technical as well as non-technical barriers are however still limiting widespread application of MDAO technologies [4]. Among these barriers, the large requirements on computational expense and complexity of organising collaboration among engineers are seen as the primary challenges [5]. As introduced by Kroo [6], to advance MDAO to the next, third generation; research should focus on addressing challenges on a computational as well as organisational level.

The increase in computing power over the last decades has opened the possibility to shift design knowledge of increased detail to early design phases. Furthermore, multifidelity approaches have been developed to address the problem of large computational expense [7]. However, this increase in fidelity leads to an increased analysis burden on the engineer, since large amounts of data are produced with increasing detail [8]. To cope with the increase in both the number of interconnected disciplines and analysis burden, collaborative design methods are pursued. The integrated design approaches currently under development are aimed at supporting groups of engineers in setting-up and analysing multidisciplinary design results collaboratively.

This paper discusses the application of such a leading-edge MDAO framework for the advanced pre-design of aircraft configurations. Furthermore, the pre-design process is set up to provide an interactive test bench for the detailed design of aircraft systems. Combining aircraft pre-design with the design of aircraft systems thereby forms a system-of-systems approach. Within this paper, the integration of system design in the aircraft design process is represented using the trailing edge high lift system as an example. First, a brief overview of the individual approaches currently applied in overall aircraft design and systems design at the DLR is sketched. Thereafter, a resulting concept for integration of both design approaches is described. The challenges faced during setting up and interlinking the workflows as well as exemplary design study results are presented. The concept for collaborative design of aircraft configurations and aircraft systems is generalised for application to overall aircraft design in the final chapter.

2 MDO FRAMEWORKS IN AIRCRAFT AND SYSTEMS PRE-DESIGN

The current chapter introduces the pursued system-of-systems approach in aircraft design. After providing a general description of the approach in the first section, the aircraft and system design approach tailored for exchanging the required data are provided in the subsequent sections.

2.1 A system-of-systems approach using distributed design principles

Within the German Aerospace Centre (DLR), a distributed design environment for collaborative aircraft design is under development. In this light, advanced preliminary design codes and technical methods for design code interfacing are generated. The established data model CPACS (Common Parametric Aircraft Configuration Scheme) provides a central model for exchanging both product and process data between design codes in multidisciplinary workflows [9]. To flexibly apply analysis modules in these workflows, Pfeiffer [10] describes an approach for 'wrapping' proprietary analysis tools to the CPACS interface. The engineering framework RCE (Remote Component Environment) supports designers in composing and executing automated workflows using the set of available wrapped analysis modules [11]. When executing a workflow, the wrapped modules are run on distributed servers located at the respective institute or external partners' site, providing the required transparency between module developers and workflow integrators. In a parallel publication [12], CPACS and RCE are further elaborated upon, including an identification of challenges for collaborative data management. Nagel et al. [13] discusses the pros and cons of establishing a common language in aircraft design.

The principles underlying the RCE framework provide the possibility to apply a system-of-systems approach in aircraft design. Figure 1 shows a schematic overview of the integration principles within this approach. In order to solve a specific design question, *operators* gather the required resources and establish a team of *workflow integrators* to technically setup the required design workflows. These integrators at their turn involve the required *system experts*, responsible for advancing the disciplinary knowledge and providing expert knowledge during the process (see also [12], [14]). For this to succeed, workflow integrators of all involved disciplines should communicate using a common language. A technical solution is provided in the form of the concurrently developed CPACS data exchange format. However, as earlier described, setting up the collaboration among engineers is still experienced as a large challenge. Defining which level of knowledge the involved engineers should have, as well as finding the required knowledge overlap bands between the user groups involved in the process is under current research. These knowledge overlap bands serve as a basis for communication between user groups and provide the possibility to convey information about interdisciplinary influences.

Since system design is very dependent on the pre-provided geometrical layout of the aircraft, limited design freedom is available in traditional sequential design approaches. To reduce development risk and time, the layout of aircraft systems shall therefore be realized early in the design process. Interlinking both aircraft and systems design during preliminary design stages might lower the possibility of having to perform expensive rework in later design stages.

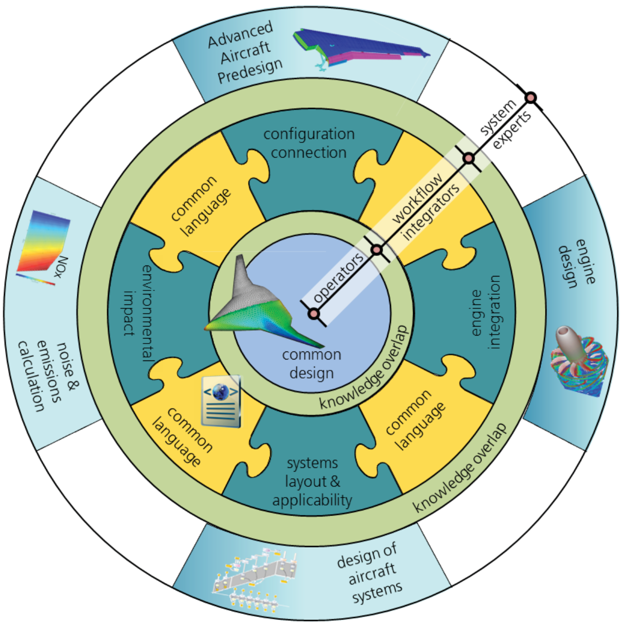


Figure 1. System-of-systems approach in aircraft design

After gaining mutual understanding of the applied design approaches, the knowledge overlapping regions are identified. Using these regions, the major interfacing possibilities are obtained and provided in Table 1.

Table 1. Overview of parametric interfaces between aircraft pre-design and systems design

	aircraft design	systems design
DATA	*interface 1*	
	CPACS	PrEMISE
INPUT	TLAR	TLAR
	high-lift requirements	high-lift reference concepts
		failure criticalities
COMMON DATA	*interface 2*	*interface 3*
	wing dimensions	high-lift concept feasibility
	types of moveables and target settings	high-lift support structure: - locations - dimensions
	secondary component: - dimensions - loads - weights	system properties: - weight - costs - power budget
OUTPUT	overall aircraft concept	systems architecture,
	TLAR feasibility	digital mock-up (DMU) (actuation, kinematics)

Using the list of interfaces, analysis workflows are established, aimed at generating the required exchange data with the required level of fidelity. The resulting workflows are schematically depicted in Figure 2, along with the identified interfaces. The fact that both approaches contain a central data format eases the integration, since this largely reduces the amount of tool interfaces to be considered.

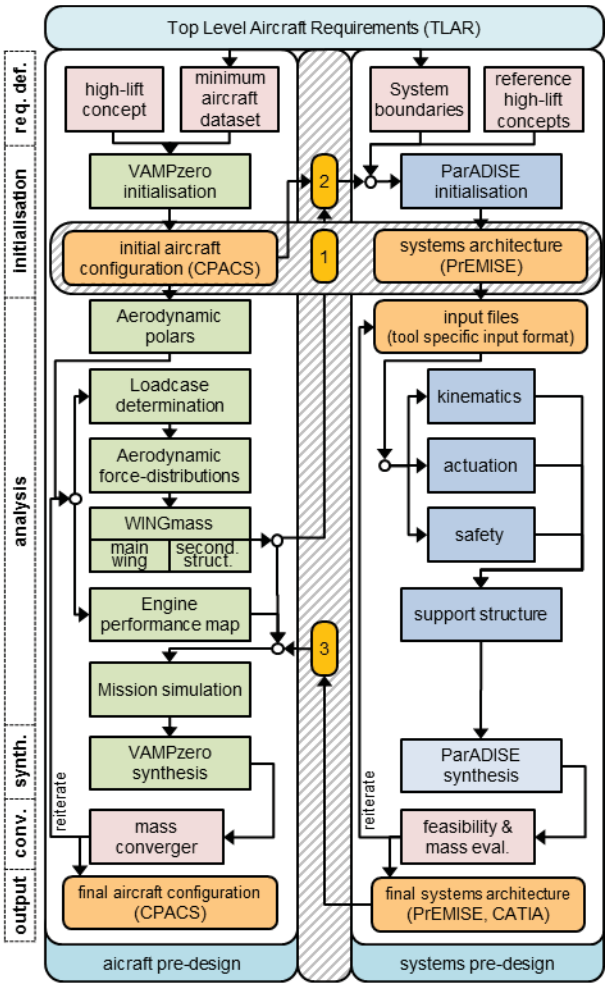


Figure 2. Advanced aircraft pre-design incorporating aircraft systems design

2.2 Aircraft design considerations

The iterative design loop is initialized by a dataset reflecting the Top Level Aircraft Requirements (TLAR), which triggers the conceptual design module VAMPzero. Within this module, the initial aircraft dataset required for initiating the subsequent calculation modules is generated using inexpensive empirical equations. As indicated in Figure 2, the selection of a high-lift concept needs to be manually added to this dataset. In the near future, VAMPzero is however extended towards providing knowledge based capabilities to add parametric descriptions of the high-lift system, through which this manual intervention becomes obsolete.

In the following analysis phase, physics based modules are run in a distributed tool network. An advantage of such a distributed network is seen in the possibility to execute data-independent calculations in parallel, thereby potentially saving considerable amounts of calculation time. Depending on the available analysis time, alternative models of different fidelity levels can be connected, enabling the trade-off between accuracy and cost of the calculation. After the analysis phase, a synthesis on overall aircraft design level is performed using VAMPzero, updating the aircraft properties while keeping the parameters calculated by the higher-order methods fixed. A mass converger finally checks for convergence of the applied multifidelity approach and reinitiates the design loop when necessary.

A short description of the tools applied in the aircraft design workflow is provided hereafter.

VAMPzero is an object-oriented conceptual design tool based on the well-established handbook calculation methods [15]. The tool enables the generation of initial CPACS data decks sufficient enough to trigger higher level methods, using a minimum amount of input data (TLAR). Furthermore, it can be used as synthesis tool for closing a multifidelity design loop, by calculating the aircraft properties not covered by higher fidelity tools.

TRIM_VL provides an interface between the CPACS data format and the freeware aerodynamic vortex-lattice calculation method AVL [16]. It triggers AVL for generating aerodynamic polars or calculates the wing load distribution for pre-provided load case(s). In the current setup, the zero-lift drag coefficient is pre-calculated, and added to the induced drag coefficients.

WeightAndBalance (WAB) creates weight and balance data for aircraft trimming purposes. The passengers, cargo and fuel are sequentially loaded to obtain centre of gravity locations, depending on the aircrafts loading condition.

LoadCaseGenerator (LCG) generates a V,n-diagram from which the main load cases to be considered during (wing) sizing are extracted.

WINGmass is a placeholder for the wing mass estimation principle applied. As described in [17], a geometric pre-processor interprets the CPACS data format and generates tool specific input data for mass estimation modules of different fidelity level. A level-1 approach bases on a beam model representation for main wing structure sizing and empirical relations for secondary structure mass estimation. Alternatively, a higher fidelity approach (level-2) can be connected, in which a full FEM sizing robot in ANSYS is applied as described in [18].

TWDat incorporates an engine database allowing ‘rubber engine’-scaling principles. This database is created using thermodynamic analyses of the engines gas generator at a multitude of operating points. By using the database within aircraft design in fact a second system-of-systems connection is created. As output, an engine performance map is delivered in CPACS, including fuel flows and emissions, depending on flight altitude, Mach number and thrust setting.

SMS is a straightforward mission simulation tool, using the aircraft geometry, the generated aerodynamic polars and engine performance map to obtain the fuel requirements for the mission to be flown. Aside required fuel mass, payload-range diagrams as well as emission values are calculated.

2.3 Systems design considerations

By means of an example, the design method on subsystem level is described within the context of a high-lift system. The design method applied at the DLR Institute of Flight Systems is based on the Architectural Design process defined in [19] enhanced by safety considerations recommended in [20]. The holistic view on the Systems Engineering process is described in [21].

As illustrated in Figure 2, the top level aircraft requirements are decomposed into system requirements which specify the boundaries of the high-lift system. Further general inputs for the design workflow are references of comparable aircraft and related high-lift concepts.

More specific inputs for the design workflow are the wing planform, the types of intended flaps or moveables, the intended target settings of the moveables for different configurations like take-off, cruise, or landing and the given failure criticalities derived with a functional hazard assessment based on expert knowledge and flight mechanics analysis. Further inputs are provided by aerodynamics and flight dynamics, such as dimensions and aerodynamic loads for every moveable component.

All mentioned inputs are considered when one or more candidate system architectures are modelled using a general architecture modelling tool like ParADISE, as described in [22]. The system architecture consists of the description, logical hierarchy, and physical connections of all involved components; like flaps, actuators, sensors, joints and structural parts. This information is stored in an open data format called PrEMISE.

Within the multidisciplinary systems design approach, different engineering models or views are derived from the system architecture. Afterwards, they are refined using a related engineering tool. The ParADISE tool is able to generate these different data files out of the system architecture described in PrEMISE. It generates a model for the multi-body simulation (MBS) executable in SimMechanics, it supports the generation of the products and parts hierarchy for the CAD tool CATIA and it supports the generation of a model for a CAE tool like Simulink/SimScape or SimXpert.

The kinematic design of the flap mechanism is implemented using a CAD tool, from which the structural model is deduced. After that, an MBS model for the actuation (power train) can be complemented and integrated with a model representing the control and monitoring concept. An FEA (Finite Element Analysis) model is used to define structural characteristics under consideration of the determined interface loads. The simulation results are used to optimize component weights, high-lift device bending (flap skew and twist), flap split positions and support locations [23]. The resulting simulation outputs represent the high-lift system's behaviour accompanied by system characteristics regarding functional performance (e.g. reaction times), interface loads, failure management, etc.

In the context of these disciplines, the process shall ensure the achievement of the following system qualities:

A. Exact achievement of predefined motion sequences or motion constraints, minimization of loads for actuation (operating loads) and structure components (interface loads)
B. Compliance to safety standards, involving exhaustive consideration of redundancy mechanisms, failure conditions and appropriate control & monitoring concepts
C. Intelligent installation – the functional component arrangement should deliver appropriate accessibility and comply to supportability and maintainability concepts
D. Functional structural design based on kinematics and installation models

The workflow to support the listed goals is illustrated in Figure 3. This workflow allows iterations between kinematics, control and monitoring, stress analysis and structural design and installation analysis. The parameters indicated in Table 2 shall be defined and exchanged with aircraft configuration design by applying the iterative design steps A-D indicated in Figure 3.

In addition to the data listed in Table 2, different cost types like non-recurring costs and direct operating costs are returned to the design team on aircraft level for further analysis.

Table 2. Definition of parameters for exchange with overall aircraft design

A	- target 3D kinematics settings - number of supports - support positions - number of flaps - flap type - fairing characteristics	kinematics type - actuation type - critical load cases - power demand - safety, reliability and availability -	**B**
D	- digital mock-up - space allocation - planform weight	wing bending - failure loads -	**C**

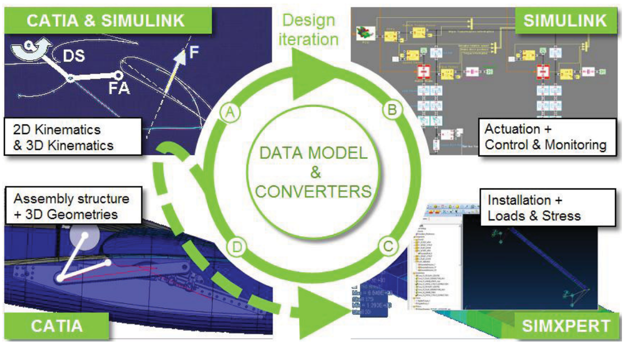


Figure 3. Setup of systems design approach and system design results in different design stages [23]

The refined results of the engineering tools are written back into the PrEMISE format using the ParADISE tool. Based on this detailed information, an evaluation is done for every system architecture candidate. As a core data model regarding systems design, PrEMISE is realized to avoid loss of information by data conversion between the tools of the involved systems analysis disciplines. This core data model is used for the integration of aspects covering the first three design stages (see A, B, C in Figure 3). A model of the kinematics (stage A) in PrEMISE is used for automated calculation of operating loads in the context of kinematics analysis [22]. PreMISE can also be used within stage B for automated generation of fault trees for safety analysis purposes [24]. Currently the research intention is to define a format for an advanced installation model incorporating kinematics and other initial geometrical information for structural design.

A short description of the tools applied in system pre-design with their specific assignment in the high lift process follows hereafter**.**

DOORS (IBM) is used to document the top level aircraft requirements, to decompose them into system requirements and to manage and trace links between documents.

VSAero (Analytical Methods) is used to define the wing planform, geometry and target settings as well as aerodynamic loads of the flaps.

ParADISE (DLR) is a system design tool focusing on modelling architectures, dependencies, and states of technical systems. It is based on an open data format called PrEMISE, which supports the data exchange between engineering tools.

CATIA (Dassault Systèmes) is used for CAD product definition, analysis of functional tolerances, kinematics definition and the creation of 3D parts, mechanical assemblies and a digital mock-up (DMU).

Simulink and Simscape (MathWorks) is used to simulate physical models e.g. for control design, dynamic system assessment with failure cases and to optimize system-level performance.

SimXpert (MSC Software) is used to analyse the effects of wing bending and failure loads.

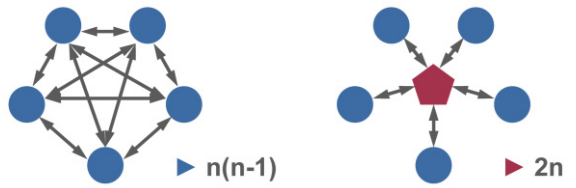
3 SETUP OF THE COLLABORATIVE DESIGN METHODOLOGY

As depicted in the schematic of Figure 2, explicit data interfaces between aircraft and systems design are identified. To generate a combined design effort, both methodologies have to be tailored for generating the required data for and incorporating data from the other. First, the differences between the central data models used in both methodologies are provided. Thereafter the practical challenges faced during the setup of the calculation workflows are described, subdivided in technical and non-technical issues. The final section describes the intended collaborative design concept.

3.1 Central data formats in aircraft and systems pre-design

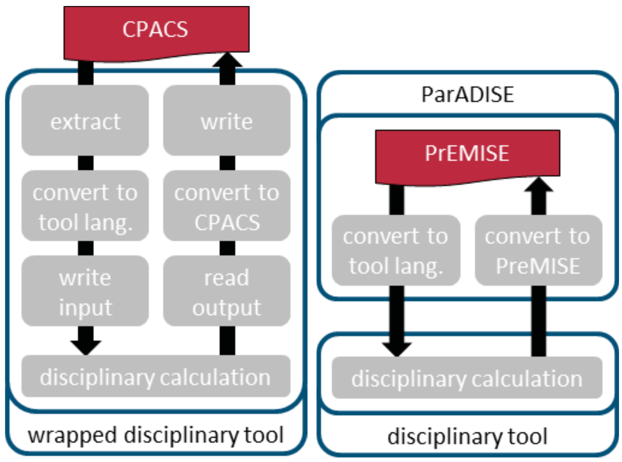
Within overall aircraft pre-design and systems layout, different data structures are used to transfer product and process data between individual analysis modules. CPACS comprises a hierarchic standardised XML based data exchange format containing the overall aircraft geometric data. PrEMISE is an open XML based data exchange format enabling the formal description of any technical systems including architecture, dependencies, and states.

Both CPACS and PrEMISE are based on the Integrated Data Model (IDM) approach [25], acting as a central "hub" between the involved engineering tools. This largely reduces the amount of interfaces to be considered when setting up a workflow, as seen in Figure 4(b). Besides the potential for reducing the number of tool interfaces, the IDM based approach enables cumulating the knowledge about the entire system in a central model. This aids in generating a common language between engineers as aspired in the collaboration setup schematised in Figure 1.



a. Pairwise approach b. Integrated data model (IDM) approach

Figure 4. General tool integration approaches showing the corresponding number of interfaces



a. Tool 'wrapping' for data exchange with CPACS b. Central specific input file generation for tools

Figure 5. Difference in disciplinary Tool integration methods in both design approaches

A difference in the application of both data formats is depicted in Figure 5. As described in section 2.1, each programmer needs to 'wrap' his/her tool to enable communication using the CPACS data format. To aid the programmer, libraries have been established to read and write entries [26] and interpret the geometric data [27] from CPACS. As a consequence, every engineer involved in the design process needs to familiarise him/herself with CPACS instead of direct coupling the involved analysis codes. In the systems design method, a central model generator interprets the PrEMISE contents and generates tool-specific input files (a similar approach is seen in the multi model generator as presented in [2]). This difference in tool integration modelling approach however does not obstruct interlinking both design workflows, since interfaces are established at the data format level.

3.2 Selection of technical issues in collaborative design

Although the software suites for interlinking design tools have evolved largely in the last decade (see [28], [29] and [11]), technical issues still remain. Even though well-established data exchange formats are available, interpretation of its contents can differ from expert to expert. Software assisting in the interpretation of (geometrical) data is under development, which should serve as a common language to resolve interpretation issues. When combining multiple design workflows, an extra challenge arises in the alignment of the multiple data exchange formats involved. Complex technical interventions are required for the proper conversion of data from one format to the other. In this conversion, extra attention is required in guaranteeing proper interpretation of the aircraft or components' geometric representations.

Another technical issue in collaborative design concerns the difficulty for disciplinary experts to create tools which are generally applicable to a multitude of geometries, load cases, etc; i.e. to create tools that are able to interpret all possible instances of the central data format. A method needs to be found for flexible tool development, in order to guarantee its applicability to conventional and unconventional geometries.

As a final technical issue to be mentioned here, some design approaches still require quite some manual input from design experts (including systems design). This hinders automating the entire interconnected design workflow, and thereby largely reduces the possible amount of iterations within an optimisation approach. Although an engineer-in-the-loop approach is proposed, the systems expert should not be repeating tedious calculations and CAD drawing generations. Instead, (s)he should observe automated calculation results, interpret these and interfere in the process when necessary.

3.3 Selection of non-technical issues in collaborative design

With the large evolution of solutions for most of the technical problems in MDAO, more attention has to be given to approaching inherent non-technical issues. These issues mainly focus on establishing proper interaction between engineers involved in the process. Easy contact should be established between the three user groups involved in the process (see section 2.1), for an efficient integration of disciplines to occur. However, Due to the difference in backgrounds and knowledge however, severe difficulties in understanding and communicating design problems can hamper the design process.

To be aided in establishing interconnections of software tools, *workflow integrators* need a standardised definition of required inputs and available outputs, along with corresponding assumptions underlying the tools. Therefore proper and transparent documentation of wrapped tools is of utmost importance. During tool execution, logbooks containing warnings and assumptions should be automatically established. This serves for general result interpretation, but more important, for debugging purposes. A change in attitude of *expert* software developers is required: (s)he needs to make sure the 'black-box' factor of the generated routine is reduced to a minimum.

When a system-of-systems approach is aimed for, extra difficulties arise, since the overall methodologies can be experienced as oversized black-boxes. This even increases the burden of having to cope with more possible sources of error and acceptance of the results of disciplines one is unfamiliar with. Unfortunately, individual work still prevails over group efforts nowadays.

Aside adjusting the communication language, disciplines historically occurring in different phases of the design should approach each other in level of detail considered. Following the trend of gaining more knowledge in early design phases, disciplines that are originally considered at the end of the sequential design chain should try to provide preliminary design tools and principles. This requires another change in attitude of the disciplinary experts, usually sceptic to providing trends based on broader assumptions.

For a more detailed elaboration on non-technical barriers to MDAO processes, the reader is referred to [4].

3.4 Concepts for collaborative design of configurations and systems

As can be concluded from the previous two sections, a lot of issues arise when establishing a multidisciplinary system-of-systems design approach. To systematically overcome these issues, it is decided to take a segregated approach. Within aircraft pre-design only the significant trends from systems design can be incorporated (e.g.: larger flap deflection angles lead to higher systems mass and power requirements, see Table 3), due to the otherwise too large demands on computational resources. For this, separate calculations need to be performed in order to identify sensitivities of systems specific output parameters to changes in geometrical layout of the aircraft. After mass convergence of each aircraft design loop, a detailed final check of the systems layout should be executed to provide an assessment of the systems concept feasibility.

Table 3. Level-0 approach to trailing edge flap systems mass estimation for transport aircraft [30](pp. 284), [31]

rotating flaps (cylinder actuation)	$5.569 \cdot (S_f \cdot \sin\delta_f)^{0.92}$	(1)
translating Fowler flaps (screwjack actuation)	$11.02 \cdot (S_f \cdot \sin\delta_f)^{0.92}$	(2)
in which: S_f =	total projected flap area [m^2]	
δ_f =	max. flap deflection angle [deg]	

During the research conducted using the design study as described in the next chapter, the possible systems design trends to be incorporated in aircraft pre-design are identified. Using the experience gained during this study, the overall holistic design approach is established. It is identified how both design systems influence each other and at which moment in the design process. After identification of emerging properties of the connected design system, the nested optimisation of aircraft configuration and systems design will be further extended in future MDAO projects at the DLR.

Since the MDAO approach is intended to be flexible in type and number of incorporated design disciplines, interpretation of calculation results should be collectively performed by the workflow integrators and involved disciplinary experts. Methods aiding in the communication between these experts are under investigation in the Integrated Design Lab (IDL), currently under development at the DLR in Hamburg [32]. In the IDL, engineers involved in the design team gather for short, intensive meetings and collaboratively approach design questions, such as the one described in the subsequent chapter.

4 INITIAL DESIGN STUDY RESULTS

The current chapter considers initial results of the overall design study: determination of the benefits of redesigning a short- to medium haul aircraft for shorter ranges. After a brief introduction in the case study, results on overall aircraft design level are described. The generated workflow contains a placeholder for the insertion of trends from systems design, which are to be generated in future studies. Currently, empirical correlations such as equations (1) and (2) are applied to determine the overall aircraft systems mass.

4.1 Case study: Aircraft redesign for short ranges

From the OAG airline schedules database [33] it can be deducted that nearly 80% of the short- to medium-range passenger aircraft are used in missions with a sector length below 1000 nm (see Figure 6), although common design and maximum ranges of these aircraft tend to be much larger [34]. Therefore, these aircraft are not optimally designed for the majority of missions operated by the airlines. To which extent redundant design range can be traded with efficiency in terms of flight performance forms the basis of the design task guiding the study. A selection of the top level aircraft requirements is provided in Table 4.

Among other effects, increasing the short range efficiency of aircraft has a large influence on the design of wings and its corresponding high-lift system. Therefore, a basis for a joint design effort is established by incorporating considerations from the design of aircraft systems in the pre-design of the aircrafts geometric wing layout.

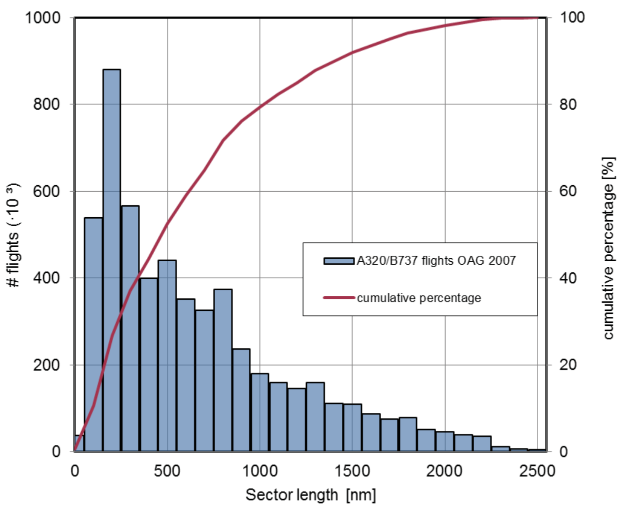


Figure 6. Sector length distribution of single aisle short- to medium range aircraft [33]

Table 4. Selection of Top Level Aircraft Requirements (TLAR) for the case study

payload	190 [pax] * 135 [kg]	all economy class with 30'' seat pitch
range	1000 [NM]	design range
takeoff field length	2000 [m]	@sea level, MTOW, ISA +15ºC
landing field length	1500 [m]	@sea level, MLW, ISA +15 ºC
cruise Mach number	0.79	
span	36 [m]	maximum
altitude	FL 350 FL 410	initial climb maximum

4.2 Results on overall aircraft design level

Within the Remote Component Environment (RCE, see section 2.1), the schematic as depicted in Figure 2 is converted into an actual chain of aircraft pre-design tools. As seen in Figure 7, interconnecting the tools in this relatively 'simple' workflow is already a complex task. The workflow consists of an initiation part, in which the initial aircraft model is generated, a high-lift concept and engine are added and the overall aerodynamic polars corresponding to the configuration are calculated. All the data is cumulatively stored in the CPACS data exchange format and forwarded to the iterative part. Herein, the initially calculated wing component masses using VAMPzero are updated using tools of higher-fidelity level. The connection to systems pre-design is established (block number 5 in Figure 7) and a synthesis is performed. The calculation is continued until the aircraft masses are converged (i.e.: all snowball effects of changing individual component masses are incorporated).

In MDAO frameworks, the trade-off of accuracy and cost associated with the application of alternative modules analysing a phenomenon with variable levels of fidelity is an important factor [5]. Therefore, the fidelity level of individual tool components can be easily in- or decreased, depending on the contents of the expert tool library and resources available to the workflow integrator. As an example, Figure 8 shows a high-fidelity alternative for wing mass determination. Calculation times increase from under a minute to about three to four hours per iteration, but wing mass results are of much higher fidelity. Since all available tools are wrapped to the CPACS data format, only the contents of block 4 of the workflow needs to be altered. This also allows the converged results of a lower fidelity workflow to be used as initial data for higher fidelity calculations, thereby possibly reducing overall calculation times.

Figure 9 shows the resulting initial aircraft configuration for short-range missions, as well as the mission profile associated with its mission.

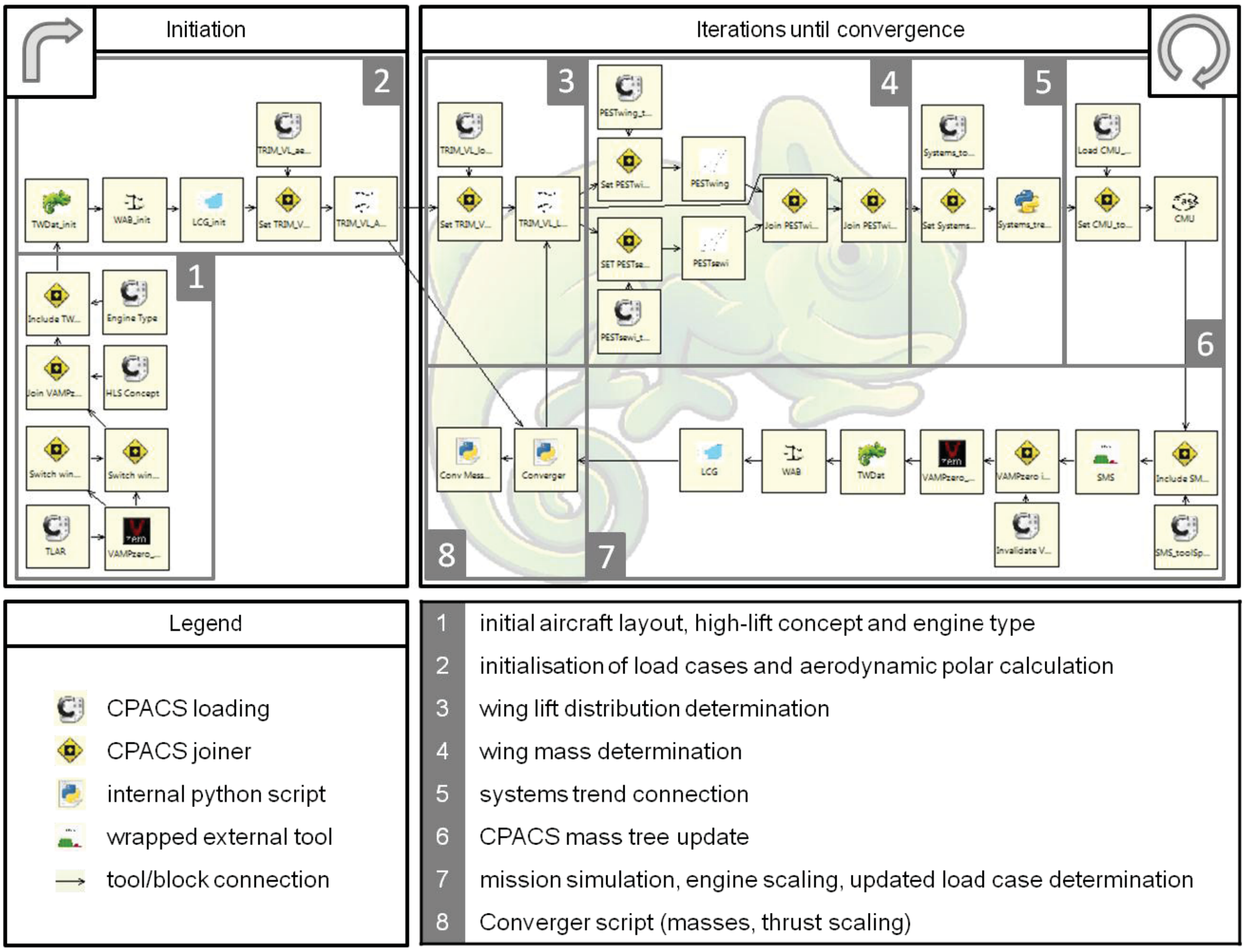
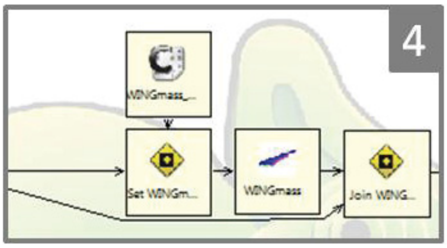
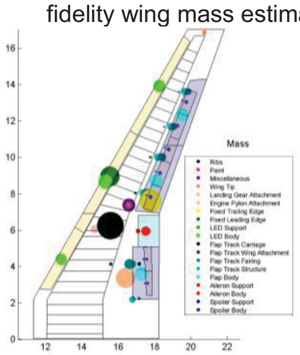
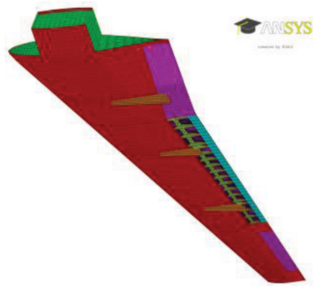


Figure 7. Multifidelity aircraft design workflow in RCE (screen capture overlaid with group subdivision)



a. Required change in workflow of Figure 7 for high-fidelity wing mass estimation

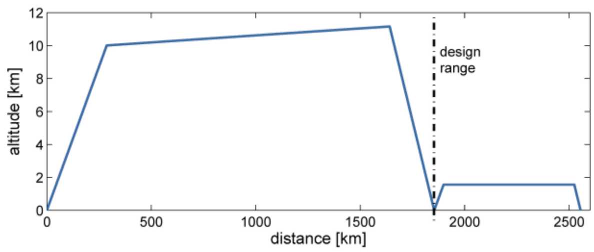




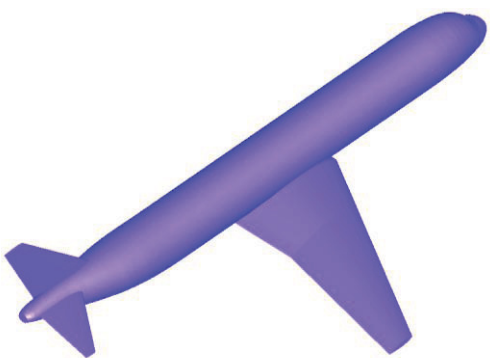
b. Secondary mass distribution determined using level-1 approach (tool: PESTwing/sewi)

c. FEM Structural model of level-2 approach (tool: WINGmass)

Figure 8. Fidelity alternatives for wing mass determination



a. Mission profile as calculated using the simple mission simulator (SMS)



b. Geometry extracted from CPACS (created with TIGL Viewer for CPACS)

Figure 9. Initial aircraft configuration for short-range missions

5 CONCLUSION AND OUTLOOK

5.1 Conclusion

Using the integration framework 'Remote Component Environment' (RCE) and by application of proper disciplinary interfacing techniques, the possibility to apply a system-of-systems approach in aircraft preliminary design is created. This was shown using a case study in which trends from the design of aircraft systems can be incorporated in aircraft preliminary design. When performing the multidisciplinary calculation, the wrapped disciplinary analysis modules are executed on remote servers. This physically supports the general approach of keeping detailed expertise at the responsible departments. Aside some inherently arising technical issues, major challenges are found in establishing effective communication between both workflow integrators and disciplinary experts with different technical backgrounds. Therefore, more focus is needed on resolving these non-technical barriers when integrating larger amounts of design disciplines in the multidisciplinary design of aircraft configurations.

By gaining more experience on the application of general methods for the detection of disciplinary interdependencies and for collaborative result interpretation, a large potential for increasing overall knowledge of the aircraft design already in early design stages is established. The large potential in improving design results by advancing the MDAO design method to a higher collaborative level should be exploited in order to face future aircraft design challenges.

5.2 Outlook

The system-of-systems approach described in this paper is still in early stages of development. Further integration of (sub)system design considerations within aircraft configuration analysis will be performed in the project 'Future enhanced aircraft configurations', starting in 2013. Aside advancing the technical capabilities of the large amount of involved disciplines and incorporating uncertainty analysis in the design, developing effective collaboration among engineers has main focus in this project.

The results of the current paper will serve as a basis for further investigations concerning the development of the technology to perform holistic aircraft design. The design of (sub-) systems will be integrated to aircraft configuration layout by implementing an automatic data interface between CPACS and PrEMISE. Thereafter, the integrated design process and the automatic data interfaces will be assessed by a use case.

Concurrently, design systems other than aircraft systems will be connected to aircraft configuration layout. Cooperation with other projects will be intensified to concurrently design an aircraft and its engines, to involve environmental emission determination in early design stages and to perform noise analysis of the complete aircraft layout.

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