EXC-SE2A: Call for Research Proposals in Research Area ICA B

Flight Physics and Vehicle Systems

1. Objectives of Call

Long-term changes in aviation policies, regulation, and energy sources will trigger considerable changes in design compared to those of aircraft currently operating. In particular, paradigms will change as a result of the considerable price differential between wind-generated electricity and refined energy carriers such as electrofuels, as will be available in future sustainable circular energy economics. Drastic reductions in aerodynamic drag and structural mass and exploitation of synergies offered by propulsion systems will be mandatory for obtaining technically feasible and economically viable designs of fully electric and electro-hybrid drive systems for aircraft with lower ranges ("short-range"). Based on preliminary design calculations, the long-term target for aircraft drag reduction is 50% and for structural mass reduction 40%, if such advanced concepts are to be utilized for commercial air transport in 2050. Mid-range and long-range aircraft, on the other hand, will continue to rely on high energy density fuels at prices much higher than the price of kerosene today. These fuel cost increases will provide a strong economic incentive for introducing these advanced technologies to improve aircraft efficiency in both short-range and long-range aircraft.

The proposed research in ICA B will explore the scientific and technological fundamentals of carefully selected aircraft technologies. The aim of the Call is to set up a comprehensive research program along the following research hypotheses:

(1) Drag reduction by systematic laminarisation of all aircraft components offers the largest potential for reducing aircraft drag and hence energy consumption. It also offers large indirect gains by exploiting snowball effects on overall aircraft design level.
(2) Research on composite materials and function integration into multi-shell structures will advance the key structural enablers of laminarisation, leading to considerable weight savings.
(3) New architectures of energy conversion on board of future transport aircraft will make the integration of advanced concepts of cooling into the structure and concurrent optimization of the aero-structural design necessary.
(4) Research on new multidisciplinary means of aircraft control will pave the way towards considerable reductions of structural weight by means of load control.

The research work will be structured into Research Units as detailed below.

Full exploitation of advances in aircraft technology knowledge requires assessment at the overall aircraft design level. Such an analysis requires flexible overall design simulations for the entire aircraft that take into account life cycle and noise impact. These simulations will not only allow quantifying possible snowball effects resulting from the introduction of new technologies, they will also identify the need for configuration changes that might otherwise be overlooked.

While overall aircraft design simulation must model the energy supply system on board, the design of this system must simultaneously consider detailed overall aircraft design data. Therefore, the simulation must be iterative and cross ICA boundaries. Therefore, overall aircraft design studies within ICA B will be closely connected to the analysis of energy systems design analysis as performed in ICA C by linking relevant analysis computation modules together, during run time of aircraft design simulation and optimisation cycles. Overall aircraft design work moreover creates important data for assessing the air transport system as a whole. These data include general performance of the ATS, aircraft performance during different flight segments, sources of noise emissions, critical engine exhaust data, direct operational costs, and others.

2. Structure of Research Units

2.1 Drag Reduction and propulsion integration (ICA-B1)

2.1.1 Objectives

Advancement of design methods, experimental data and analyses during the first funding phase of the Cluster of Excellence justify setting up far-reaching research objectives beyond the focus of current drag reduction technologies. Based on design studies on overall aircraft level careful estimates of flow-laminarisation potentials and corresponding reductions of induced drag offer large possible drag reductions, in the order of 50%. These large gains will be only achieved, if advanced methods and new design knowledge are created in 3D flow design and interactions of external aerodynamics with the suction flow are well understood. Aerodynamically efficient long-range aircraft configurations present particular challenges in aerodynamic propulsion interactions, in predicting noise levels from tonal and broadband sources as well as noise transmission through shell structures. Hence, noise prediction methodology based on Computational Aero-Acoustics and dedicated validation shall be established.

2.1.2 Work content

Determination of the optimum amount of laminar flow on future transport aircraft requires advanced design methodologies and new design knowledge. For efficient design cycles the methodologies shall comprise simulation models of different levels of fidelity that cover the expected flow behavior. Special focus shall be paid on simulation models that predict boundary layer transition and the effect of flow control for fully three-dimensional boundary layers. Integrated design explorations shall identify optimum pressure distributions for high-speed flows of 3D swept wings, taking into account the internal suction flow through tailored sandwich structures provided by Research Unit ICA-B3. Dedicated research shall be applied to the problem of exploring the design space of the laminar fuselage, by covering both, the design of suited geometries and optimum suction strategies. The numerical design exploration will build on experimental validation of transition predictions for fully 3D boundary layers, and the effectiveness of flow control by suction for boundary layers with both Tollmien-Schlichting and cross-flow instabilities present. These experiments shall employ a laminar wing section, mounted in the DNW-NWB wind-tunnel of DLR that features well-designed 2.5D and 3D flow fields. Moreover, experiments shall be established by which the ability of advanced suction surfaces to control flow instabilities for sustained laminar flow on fuselages are demonstrated.

Propulsion integration shall be considered for improving propulsive efficiency of upper wing-surface integrated engines of blended wing-bodies. While the first funding phase generated detailed knowledge on the sensitivities of laterally stacked inlets, the next phase should perform research into optimal nozzle geometries that minimize mixing losses for asymmetrical engine flow paths. Note that novel concepts of boundary layer ingestion will be covered by other collaborative research programs at TU Braunschweig, and therefore, shall not be considered.

Possible augmentation of aircraft sound levels by propulsor noise due to highly integrated propulsion systems calls for assessment with non-empirical, yet efficient simulation approaches. While an efficient method for tonal noise has resulted from research during the first funding phase of the Cluster, broadband noise generation by turbulent flow interactions shall be covered in the next step, thereby allowing to take both noise sources into account during future aircraft design cycles. The extended model shall be applicable for quantifying noise levels of ducted and non-ducted propulsors. The transmission of sound-generated noise through shell structures into the cabin of commercial transport lacks validation through comprehensive experiments. Such validation shall build on a carefully designed strategy of structural and aero-acoustic test setups of deterministic and stochastic load transmission through a representative fuselage shell.

2.1.3 Estimate of resources within Research Unit

The overall personnel resources for establishing the Research Unit are 6-8 doctoral researchers.

2.1.4 Call coordination

The Call to define Research Unit ICA-B1 is monitored by a Call Coordination Team composed of PI Rolf Radespiel and program manager Svenja Bartels. The team members will serve as points of contact for any question concerning this Call.

2.2 Load Control (ICA-B2)

2.2.1 Objectives

The wings of aircraft are designed to sustain all aerodynamic loads during flight, and these requirements directly influence structural weight. Reducing aerodynamic loading will reduce this weight. In the ultimate case of the 1g-wing, the wing structure is sized for non-accelerated 1g horizontal cruise conditions only, assuming that an appropriate load alleviation technique adapts the wing to sustain all loads deviating from this 1g case. The 1g-wing relies on the ability to rapidly shift the centre of lift in-board and on providing effective lift dump as well. Such drastic aerodynamic manipulation for achieving weight reduction of the 1g-wing concept is a truly multi-disciplinary research challenge: only if aerodynamics, structure, flight mechanics, sensor and actuator systems as well as control concepts, are deliberately interlinked with sufficiently high precision can the weight reduction potential come into reach.

Multidisciplinary numerical simulation can be used to explore the sensitivities of aerodynamic, structural, and system concepts including their interactions in order to achieve the required rapid redistribution of aerodynamic forces during aircraft manoeuvres and gust/turbulence encounters. The first funding phase of the Cluster has resulted in the fundamental characterization of passive load alleviation concepts based on elastic wing structural designs with non-linear aeroelastic response, as well as novel flow control concepts based on fluidic actuators for fast, active lift dump. In addition, flight-mechanical modeling capabilities were developed that enable study of load alleviation systems on full aircraft configurations in real-time, including sensors with stochastically modeled input, robust controller strategies, and multiple implemented actuators and passive structural concepts. The objective of the research of the second funding phase of the Cluster is to substantiate feasibility of drastic load reductions by optimizing the topology and hence, synergies offered by passive and active means for load alleviation, and to investigate the potentials of fusing data for multiple sensors and multiple actuators in advanced load control concepts, that take into account stability and aeroelastic response of high-aspect ratio wings.

2.2.2 Work content

Previous research works of the Cluster have identified passive means to alleviate wing loads using nonlinear behavior of future materials and by exploiting the potentials of elastic structural deformation. On the other hand, novel fluidic actuators were devised that yield very fast response, albeit with limited amplitudes. One objective of the second funding phase of the Cluster will be to devise hybrid load alleviation by joint aero-structural approaches that combine passive and active means of load re-distribution and load reduction. Such potentials hybrid load manipulation shall be demonstrated for major parts of the flight trajectory, covering transonic cruise and subsonic low speeds.

The advantages from reduction in structural wing weight must not be lost to larger additional energy consumption and/or system weight. One hypothesis is that combination of forward-looking LIDAR and sensor networks integrated into the wings and fuselage will facilitate accurate evaluation of the aircraft current and future state. Previous research of the Cluster has resulted in a capable aero-elastic and flight mechanics model including structure, aerodynamics and actuation. Optimum control architectures to be devised in the second funding phase shall take advantage of data fusion from LIDAR and networks of local sensors on board to generate precise estimates of the aircraft's state physical flight behavior. An appropriate active system shall be devised based on this modelling that addresses boundaries of flight envelopes, handling qualities, flutter suppression, divergence, and load alleviation of high-aspect ratio wings. The investigations shall take into account the novel hybrid aero-structural wing topologies that will result from the above described work in the Research Unit.

PIs of the Research Unit are encouraged to consider verification of critical components of load alleviation by subscale flight tests. Such experiments shall build on the subscale flight demonstrator of the mid-range reference aircraft that was developed during the first funding phase of the Cluster. Proposals into this direction shall be limited to verify clearly defined alleviation functions or well determined components of the load alleviation system, so that such technology verification becomes feasible.

2.2.3 Estimate of resources within Research Unit

The overall personnel resources for establishing the Research Unit are 5-6 doctoral researchers.

2.2.4 Call coordination

The Call to define Research Unit ICA-B2 is monitored by a Call Coordination Team composed of PIs Rolf Radespiel, André Bauknecht and program manager Svenja Bartels. The team members will serve as points of contact for any question concerning this Call.

2.3 Shell structures and materials (ICA-B3)

2.3.1 Objectives

The research on advanced shell structures and materials aims at incorporating multiple-shell structures with integrated functionality into the load path of swept wings and fuselage. Functionally integrated structures with suction capability require new design concepts, enhanced models of structure, and models of intended functions on different scales of resolution. The research works of the first funding phase focused on exploring the potentials and limits of a range of additive manufacturing variants for realizing fluidic functions, and the design sensitivities of integrating suction panels into non-swept wings were also determined. The design goal of the second phase is to advance integration of fluidic function defined by aerodynamic design of laminar wings to the next level. The goals are lightweight wing structure and compliant manufacturing processes of suction inserts for the swept wing of high-speed transport aircraft, offering weight savings of at least 10% relative to current structure designs.

2.3.2 Work content

The concept of structural integration of laminar flow control employs multifunctional multi-shell sandwiches. The sandwich comprises fluidic chambers needed to control suction pressure differentials under the skin, and (in case of suction inserts at the nose) it must function as crash structure to cope with bird impact during flight, whereas integration of a suited de-icing function must be also feasible. The designs of complying suction inserts shall build on wing section geometries and numerical models of the suction fluid functions, as developed during the first funding phase in ICA B1. One goal is to quantify potentials and limits of integral additive manufacturing with complying materials versus differential concepts that employ advanced bonding processes. While the multi-walled suction concept provides a lightweight structural solution, integration into a swept wing has to fulfill a range of further requirements in order to substantiate weight saving potentials. Optimized swept wing designs shall take suited representations of high-lift systems into account, and shall consider realistic estimates about the required manufacturing accuracies and e.g. seals.

Technology verification shall be provided on several levels. These comprise tests of compliance with respect to outer surface quality, the homogeneity of the achieved suction orifices, the graded pressure inside the sandwich below the suction skin, and the mechanical properties of integral and differential manufacture. Functional coupon tests could help verify impact simulations from bird strike. The work of the Research Unit B3 shall provide a suction insert for the swept wing experiment planned by RU B1 as a mandatory output.

2.3.3 Estimate of resources within Research Unit

The overall personnel resources of the Research Unit are 4-6 doctoral researchers.

2.3.4 Call coordination

The Call to define Research Unit ICA-B3 is monitored by a Call Coordination Team composed of PIs Rolf Radespiel, Martin Wiedemann, and program manager Svenja Bartels. The team members will serve as points of contact for any question concerning this Call.

2.4 Collaborative and multidisciplinary aircraft design methodology (ICA-B4)

2.4.1 Objectives

The traditional sequential methodology in use for designing aircraft components and systems poses several serious challenges for the design of next-generation, more complex aircraft architectures. These challenges are rooted in the problem that such designs face a lack of prior engineering knowledge, that multidisciplinary design work has to be based on consistent model fidelity, and that there is the need to rely on distributed and iterative design efforts that call for frequent model synchronization. These challenges shall be addressed by collaborative research of the SE2A Cluster, enabling distributed multidisciplinary design optimization within a multi-level and multi-fidelity framework that can handle consistency of models and model synchronization. Dedicated efforts will be spent on the need to share and re-use distributed background knowledge of the design participants, e.g., through a knowledge-based engineering framework. The collaborative design methodology will be employed and examined to solve the problem of integrating functions of cooling into the load carrying shells of future long-range transport aircraft.

2.4.2 Work content

The working hypothesis of devising a collaborative, multidisciplinary design environment assumes that all essential tools are integrated in an open-access simulation framework, e.g. Kratos, that provides necessary tools of communication to facilitate coupled design simulations as well as data storage and data representations, as needed for e.g. multidisciplinary optimization. Core of distributed design efforts shall be the joint geometrical representation, the Master-Model, that can be accessed by all stakeholders. The CAD kernel of the Master-Model shall be generated by a well-suited software, e.g. Catia, and sophisticated to different levels of fidelity, as needed in different domains of the problem. The design environment shall offer access to solvers for simulating the relevant components on various levels of fidelity, as needed to guarantee model consistency, and enables flexible coupling via field quantities. The design environment also offers access to sound representations of uncertain parameters, data and tools for monitoring uncertainty and the propagation of errors through the design process. The design environment shall further provide the stakeholders with a sound methodology to exchange their background knowledge with each other as needed to provide frequent synchronization of the design.

The design environment shall be used to integrate extensive cooling function into suited shell structures of future long-range transport aircraft, in order to provide the needed heat sink for low temperature waste heat of the thermal system. Such design shall be based on a suited system simulation of the cooling cycle, as originated in ICA-C. The heat sink function shall be represented as a three-field problem of fluidic cooling channels, the load carrying shell, and the outer aerodynamic flow. The optimization problem shall take into account aerodynamic interactions of the outer flow field that affect lift and drag of the aircraft, the task of minimizing the weight of the shell, and the task to optimize the use of a given temperature difference to the external flow. Optimization shall address various means to intensify heat transfer rates, that would lead to minimum surface area and extra weight of the heat sink function. However, the overall aircraft design process shall not be considered.

2.4.3 Estimate of resources within Research Unit

The overall personnel resources for establishing the Research Unit are 5-6 doctoral researchers.

2.4.4 Call coordination

The Call to establish Research Unit ICA-B4 is monitored by a Call Coordination Team composed of PIs Rolf Radespiel, Ulrich Römer and program manager Svenja Bartels. The team members will serve as points of contact for any question concerning this Call.

2.5 Long-Range Aircraft Configurations and Technology Analyses (ICA-B5)

2.5.1 Objectives

A comprehensive analysis of new aircraft configurations for long range air travel is important to overcome the limitations of current designs in terms of economic feasibility and compliance with environmental objectives. Moreover, such configurations serve as reference aircraft to analyze the potentials of novel aircraft technologies, as developed within the Cluster with consideration given to often conflicting economic and environmental objectives. The group will work in close collaboration with the Cluster's fundamental research thrusts in the fields of aerodynamic drag reduction, noise reduction, weight reduction, and new approaches for energy storage and conversion. The Research Unit shall establish a sophisticated Design Engineering Engine (DEE) based on state-of-the-art optimization methods for preliminary aircraft design. DEE will provide the means of simulating the physical effects of selected technologies and their interactions on fully iterated aircraft of sufficient maturity. DEE shall be linked to computation modules of the SE2A Cluster for sizing the energy system on board, and for assessing noise, life-cycle costs, and environmental impacts in order to gain a sufficiently broad view on newly developed technologies. The overall design analysis will provide scientifically sound assessment of technology advances by EXC SE2A and assist the Principal Investigators in devising well-informed decision making on continuous research efforts to be pursued by SE2A.

2.5.2 Work content

Two major research directions are foreseen:

(1) The conceptual design of future long-range aircraft will combine medium-fidelity and physics-based methods such as simplified FEM and efficient 2.5D flow simulation tools, tightly coupled with an overall aircraft design methodology such as SUAVE. Efficient computational chains in this respect are available from previous works of the present design team of the Cluster. The methods shall be used for conceptual design of long-range aircraft configurations comprising classical tube-and-wing, classical Blended Wing Bodies, Hybrid Wing Bodies, and Flying-V configurations, and for analysing their potentials and limitations from perspectives of environmental impact, costs, flight dynamics and control, noise prediction and other important aspects.

(2) Higher-fidelity methodologies need to be developed that address the simulation of design features of future long-range configurations beyond the current knowledge and methods used for conceptual design. These comprise the simulation of the high-fidelity aero-structural analysis of unconventional aircraft, the aeroelastic assessment of unconventional configurations, the integration of models of on-board power networks (the latter being developed by other research teams in the Cluster), as well as physics-based modeling of future hydrogen fuel tanks on board.

Such a multifidelity design and assessment shall be developed by the Junior Research Group "**Long-Range Aircraft Configurations and Technology Analyses"**. Such Junior Research Group could probably take advantage of collaborating with an additional research project on the design fundamentals of cryogenic hydrogen fuel tanks.

2.5.3 Estimate of resources within Research Unit

The overall personnel resources for establishing the Research Unit are 2-3 doctoral researchers and one JRG lead position.

2.5.4 Call coordination

The Call to establish Research Unit ICA-B5 is monitored by a Call Coordination Team composed of PI Rolf Radespiel and program manager Svenja Bartels. The team members will serve as points of contact for any question concerning this Call.