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Technology Integration for Future Aircraft Configurations

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Abstract

Recent ambitions towards massive emission reduction on future aircraft trigger a range of technical disruptions. This is putting severe challenges on how the technology will be modelled, simulated and validated and how these technologies are integrated as architectural solutions in the future product. Disrupting approaches such as ultraefficient airframes and propulsors or complete new architectures for novel sustainable energy carriers require a holistic approach considering all parameters of relevance simultaneously, including the industrialization and certification dimension.

Next generation methods, tools, processes and related physical validation approaches are required to master the significant risks and uncertainties of novel technology bricks, especially in areas where solutions or even benchmarks are still missing.

Keywords: Aircraft Configuration, Overall Aircraft Integration, Virtual Product, High-Fidelity Testing

1. A novel design approach for disruptive architectures

Recent ambition towards massive emission reduction on future aircraft triggers a range of technical disruptions. This is obviously valid regarding the technology set to be developed, but also putting severe challenges on how the technology will be modelled, simulated and demonstrated and how these technologies are integrated as architectural solutions in the future product. A classical sequential design approach is not possible any more, as - different to previous products - an evolution out of well-established solution ranges is not sufficient. Disrupting approaches such as ultraefficient airframes and propulsors or complete new architectures for novel sustainable energy carriers - such as hydrogen - require a holistic approach considering all parameters of relevance simultaneously.

In the latest new product developments by Airbus such as the A350XWB or major derivatives such as the A320NEO and A330NEO a multidisciplinary design optimization based on the competence and experience of all involved disciplines has proven its high fidelity. Digital simulation means have confirmed their applicability and experimental means have changed from being only major tools for design verification towards being benchmarks of the digital design simulation means and processes. The final proof for design maturity and compliance relied on dedicated test campaigns, most visibly in the ground tests (e.g. the “iron birds”) & flight test experiments leading finally to the certification of safe and compliant products. Upfront integration of industrial constraints into the design parameters was considered, but a full concurrent “design to industrialization” was limited in the depth of the possible process modelling. Besides this, also the consideration of all certification relevant aspects already in the conceptual and preliminary design phase was naturally limited, leading to classical “aft-loaded” activities for validation in dedicated testing activities for validating the converged design solutions.

For future products, next generation methods, tools, processes and related physical validation approaches are required to master the significant risks and uncertainties of novel technology bricks, especially in areas where novel solutions or even benchmarks are still missing. Examples of disruptive architectures providing foundations for future "sustainable" aircraft concepts are e.g. ultraefficient airframe concepts (e.g. including laminarity and extreme high aspect ratio active-adaptive wings), ultraefficient propulsion concepts (e.g. open fans) and novel energy carriers (such as hydrogen, with complete new storage and supply system architectures).

2. An integration challenge: Ultraefficiency as key enabler towards sustainability

Ultraefficiency is a central contributor towards more sustainable future aircraft concepts. Significant fuel burn reduction is possible by advanced technologies reducing drag and weight far beyond today’s product standards. The related fuel burn improvement directly benefits the CO_2 emission impact when still forced to largely operate with fossil fuels in the oncoming transition period. It also mitigates the foreseeable significant increase of energy costs, either by market mechanisms or also by oncoming regulations.

“Sustainable” fuels such as synthetic drop-in kerosene or hydrogen will finally mitigate the direct CO_2 emissions, however its supply will be also in long term visibly more expensive. Disruptive energy carriers such as hydrogen will need to be stored in different architectural arrangements, which will make known aircraft configurations such as “tube & wing” arrangements less efficient. In this case fuel cannot be stored any more in the wing, but cylindrical cryogenic tanks need to be arranged within the fuselage. This significantly impacts the transport efficiency by less available volume for passenger and cargo, except if the fuselage component is upscaled with the obvious drawbacks on weight, drag and complexity. The adverse snowballing of these effects can be countered only by a significant efficiency gain, reducing the need for propulsion energy on board, subsequently limiting the required space and weight for storage systems. Ultraefficiency can be therefore considered as the central affordability enabler, especially also for aircraft operating with future sustainable fuels, such as the Airbus ZEROe concepts.

Figure 1: Airbus ZEROe concept aircraft

2.1 Future high performance wings

In following, as a key example for aircraft level driven integration considerations of future technologies, the wing component is considered:

The wing design of Airbus aircraft has undergone significant evolutions, yielding as today's state of the art the multifunctional wing of the A350XWB [1]. This wing design consists of a targeted "design-to-peak performance" approach including in-flight variable camber profile adaption capability combined with an advanced CFRP structural concept. Also load control functions were enhanced beyond the previous capabilities with a targeted in-flight setting of the trailing edge moveables, according to flight conditions.

A next generation wing will need to enable another step change towards energy efficiency, while a proper trade-off between a maximum performance gain by dedicated technology while keeping a still attractive industrial and operational affordability needs to be carefully considered.

For friction drag reduction the application of laminar flow technology is advanced and already well proven and rather a matter of managing the remaining industrialization challenge and ensuring the operational compliance to operator's requirements.

For induced drag improvement the last product generations have already undergone the development towards higher aspect ratio wing concepts, either via planar span increase or dedicated wing tip devices. Performance benefits from span extension are usually counterbalanced by weight increase from growth in wing root bending moments, which had to be mitigated by advanced wing load philosophies and structural concepts to ensure a net benefit is remaining. Active control technologies, up to fast closed control loops for maneuver and gust load management will further shift the boundaries and combination of passive load control by targeted use of the anisotropic properties of CFRP designs (aeroelastic tailoring) will enable significant increase of aspect ratio limits versus today's aircraft.

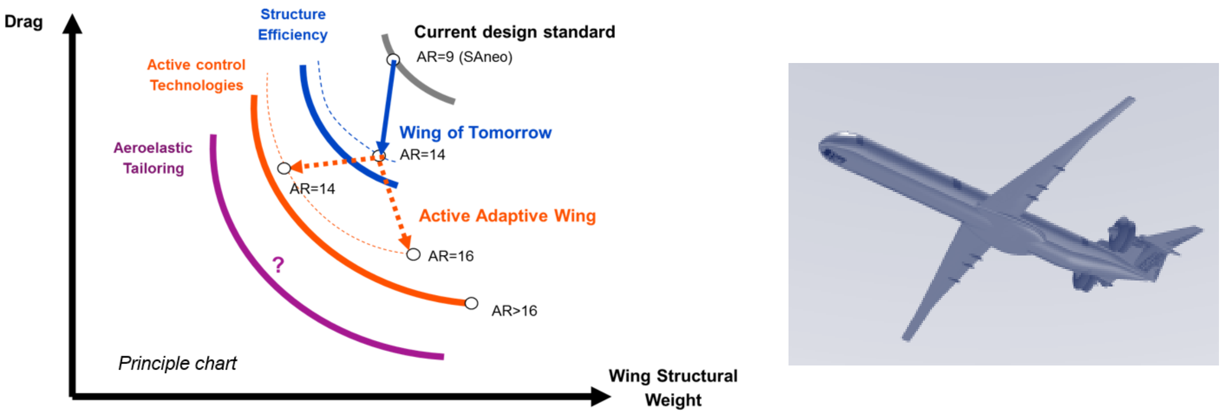

Figure 2: Increased aspect ratio to further optimize drag

The drawback on the last mentioned points is on the system complexity and the CFRP design and manufacturing competence. Dedicated investments in these technology fields are required to enable the maturation of the principle flight physics & flight dynamics potentials of high aspect ratio wings.

2.2 Overall aircraft integration drawbacks

A future ultraefficient wing likely will incorporate these technology bricks. However, for an optimum exploitation of its benefits, also the Top Level Aircraft Requirements (TLAR) may be reconsidered. The well-established design points of today's products in terms of design range and cruise Mach number may therefore need to shift. A careful consideration of the product operability within given fleet operational and air traffic management systems is therefore important to avoid adverse effects, hampering the full exploitation of the offer for increased efficiency.

Two selected examples are given for such adverse drawbacks:
1) Higher aspect ratio wings will lead to increased span and therefore will result in incompatibility to given gate classes at airports (e.g. Code C: 36m box for 737 / A320 class aircraft). As enabling technology a foldable wingtip could be applied, which however puts additional system weight and complexity.
2) Optimum natural laminar flow conditions on the wing require reduced cruise Mach numbers vs todays short/medium range aircraft standards. This results in increased block-time which needs to be counterbalanced e.g. by improved ground operational procedures, such as the turn-around time, and potentially by adapted air traffic management procedures to maintain the same bottom line transport efficiency of this product.

This means that in this - and many similar - cases the overall challenge to mature efficiency gains lies not on technology brick level, but on the overall aircraft design or even the overall aircraft operational system level. However, in a design approach focusing on a synergetic combination of design parameters also benefits can be raised.

The optimum cruise speed as example for an overall aircraft integration driven approach:
1) As mentioned, natural laminar flow results in lower cruise Mach number design versus current short/medium range aircraft as its wing design requires lower wing sweep angle.
2) Integrated high aspect ratio wings most likely need to be oversized in terms of wing area due to the need for achievable landing gear and moveables integration constraints. They operate therefore in optimum at higher lift coefficients vs current designs. Keeping current cruise altitudes (e.g. as limited by engine sizing) would therefore mean flying slower as well to exploit the full benefit.
3) Related future high-efficiency open rotor propulsion concepts aim to operate as well as slower cruise speeds, where their noise impact & efficiency is better.
4) Take-off propulsive efficiency is key to reduce propulsion system weight & cost. A high-aspect ratio wing which is already oversized in terms of wing area due to integration constraints can therefore reduce the required installed engine power, leading to beneficial snowball effects on engine sizing, i.e. weight, cost and specific fuel consumption.

Also future “eco-driven” flight operational aspects need to be considered and optimized in a close coupled way. Novel flight operations will be required for low noise in airport proximity and advanced trajectory management in cruise flight, incl. the “off-design flexibility” to address global warming parameters such as particle emissions or contrails avoidance by trajectory management or also the ability to operate in formation flight. These operational concepts are “moving targets”, being optimized in conjunction with the aircraft concept and its technological solutions. Tradeoffs between an extremely optimized design point and improved flight operational “off-design” flexibility become imminent and may lead to different technological solutions than a classical design approach. As example, a wing concept with highly multifunctional control surfaces may become superior via those off-design operational drivers, despite the additional complexity required.

A future aircraft concept therefore may be built on a range of major technology bricks which yield a synergetic optimum. Figure 3 provides an illustration of such a hypothetic concept built on an extreme high aspect ratio active-adaptive wing, natural laminarity and open rotor propulsion.

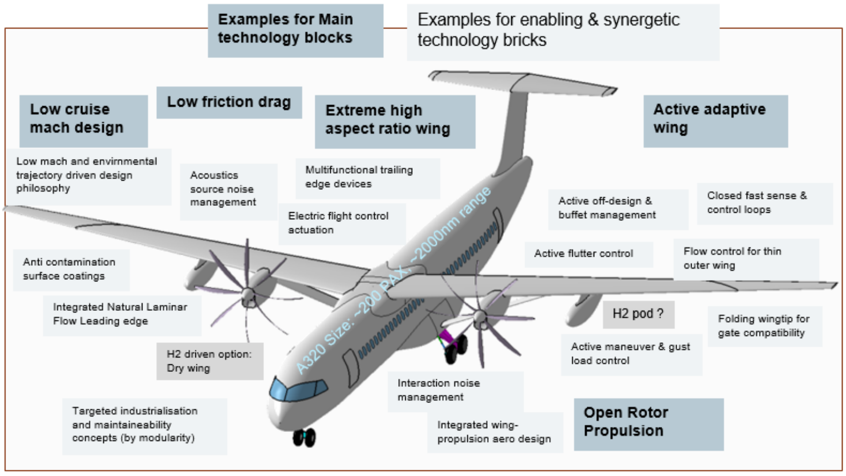

Figure 3: An ultraefficient aircraft concept

2.3 Underlying technology challenges

Even if a promising overall aircraft concept is found, the design maturation of an aircraft level integrated concept is a challenge still requiring significant advances in technology development. All major design disciplines need to contribute beyond today's level of fidelity, therefore a targeted investment in concept verification, functional demonstration and related tools development is mandatory as prerequisite and foundation for the incorporation of this design philosophy in a future product. Figure 4 summarizes the major challenges for a high aspect ratio wing.

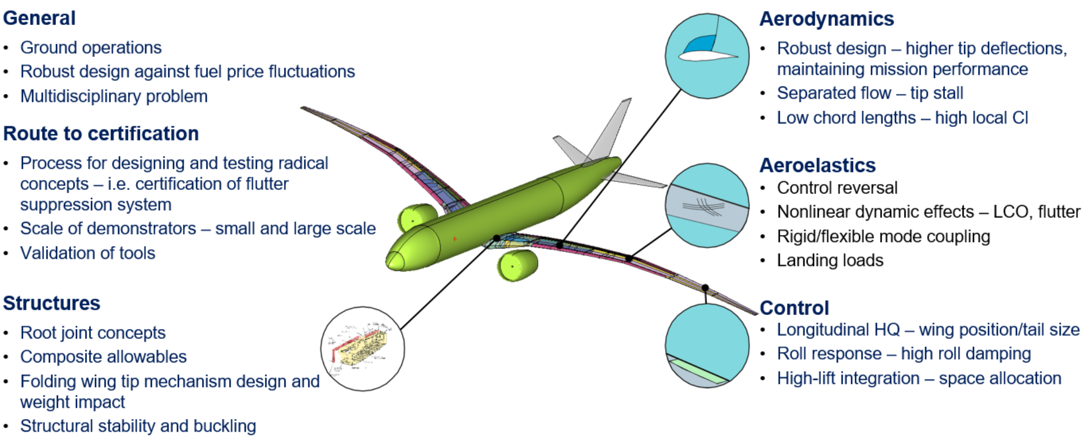

Figure 4: Technology challenges for the development of a high aspect ratio wing

3. High fidelity benchmarks

A comprehensive set of emission-efficient technologies can be considered as highly attractive and in various cases already as in principle viable for next aircraft generation. But the crucial stepping stone for the product readiness requires a sufficient degree of high-fidelity validation. Extrapolation from existing knowledge bases and use of simulation tools benchmarked with today's data and experience is not sufficient. This situation resembles to the era of the demonstration of novel breakthrough technology via "X-Planes" in the 1950...1960'ies. However, the major difference is the conjunction of nowadays the cutting edge simulation technologies. The high-fidelity benchmarks therefore are not required as the single and ultimate proof as in former times, but mainly as foundations for the tools & processes which then form the workbenches to design the next generation products.

3.1 The BLADE laminar flow flight test demonstrator

One prominent example of the high-fidelity demonstration effort required is the recent large scale demonstration for natural laminar flow on the A340 BLADE Flight Test Demonstrator in Clean Sky 2 [2], which paved the way towards industrial application readiness in a next product. Although many ground test on component benches or windtunnels have been conducted before, the flight test results could not have been be derived in small scale testing of computational simulation. The findings at full scale representativeness under real operational constraints have proven the applicability and performance of the selected solutions. Observed differences towards subscale testing and numerical simulation confirmed the importance of this demonstration. In turn, an invaluable high-fidelity set of benchmarks is now available to set the “cornerstones of the solution range” and provide full confidence in the trade-offs for the convergence of a future product’s design and build concept, and the related expected performance gain, to ensure best efficiency vs a best-balanced related effort in industrialization, operability and maintainability and the related costs.

Figure 5: BLADE flight test demonstrator for natural laminar flow wing technology

3.2 The extra performance wing flight test demonstrator

Another recent example for an approach to an early high-fidelity benchmark is the Airbus “extra performance wing” flight test demonstrator, which is currently in progress of being prepared for an in-fight benchmark of a disruptive wing concept as technology brick for the next aircraft generation. It is focused on accelerating and validating technologies that will improve and optimize wing aerodynamics and performance for any future aircraft. This scaled demonstrator will integrate and fly breakthrough wing technologies on a Cessna Citation VII business jet platform in representative flight conditions. The applications of the extra-performing wing would be compatible with any next generation propulsion solution and aircraft configuration. Based on a very high-aspect ratio wing concept various technology bricks will be investigated to enable the active control of the wing, including: gust sensors, pop-up spoilers or plates that are rapidly deflected perpendicular to airflow, multifunctional trailing edges that dynamically change wing surface in flight and a so-called semi-aeroelastic hinge.

This demonstrator aims on a functional proof of the disruptive features required to enable an active-adaptive controlled wing, deliberately aiming to demonstrate extreme solutions. For a future aircraft program solution, best-balanced solutions can then be selected out of this “technology menu”, significantly lowering the related risks on the technology selection, while minimizing the previously usual large margins taken at introduction of advanced technology solutions. The functional proof also provides an upfront confidence on the safe operability and the certifiability of the novel solutions, by giving early means of compliance for direct verification of the technology brick itself, or proofing the applicability of the related simulation tools and processes in the following product design period.

Figure 6: Airbus extra performance wing demonstrator arrangement
on the Citation VII platform and first windtunnel tests

3.3 The modular wing-moveables testing approach

Not only flight test benchmarks are applicable to set the cornerstones of novel technology bricks and their validity ranges. Targeted novel ground test bench approaches can provide important early proofs for design solutions which are still in its convergence phases. Full scale ground bench testing was previously conducted rather late in the development process, usually for validation of the design solutions against the design specification and demonstrating compliance for certification. Unnecessary margins not possible to disclose in the preceding design & simulation approaches however could not be easily removed when design solutions were already quite advanced in its convergence.

As example, Airbus future wing-moveables technology development put an early modular test bench in practice, which resembles the functionality of the classical certification test benches, however has a high modularity to represent a large degree of parameter variability, instead of being only representative for a single converged design solution. This bench provides central input for a related following hybrid-virtual testing approach which then provides early proof and design validation for design convergence with significant frontloading in the development process.

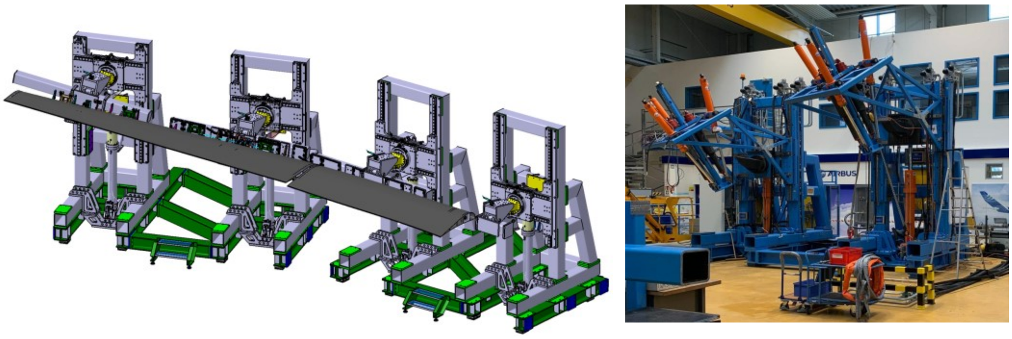

Figure 7: Modular testing bench for future Airbus wing-moveables design solutions

3.4 The A380 hydrogen propulsion demonstrator

Even more disruptive technologies such as hydrogen propulsion concepts will have to undergo an even far more steep maturation path to confirm the validity of the expected benefits and to develop a complete new set of capabilities not available so far at all. Also in such cases the interrelation with the overall aircraft architecture or even the overall product design paradigms is in closest mutual dependency.

In this context an A380-based flying testbed for a hydrogen propulsion architecture was recently decided and is in preparation process. This full scale proof of a fully integrated hydrogen propulsion chain is a mandatory brick for Airbus' intents for a product readiness for the ZEROe in the mid of the next decade. It provides a "shortcut" approach, compared to classical separate demonstration of individual building blocks and aims directly to demonstrate the viability of the full propulsion chain from cryogenic hydrogen storage over distribution and control to a hydrogen combustion jet engine under relevant operational conditions.

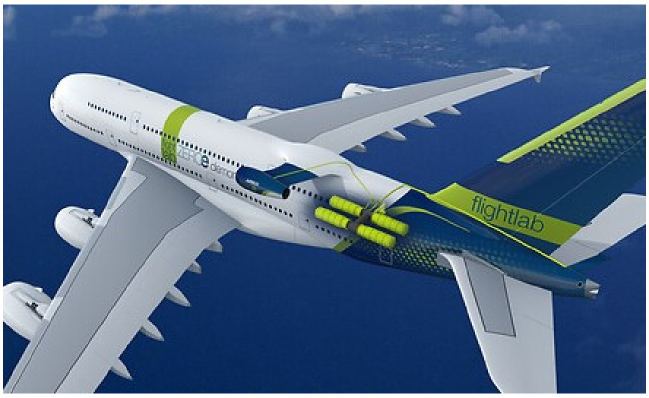

Figure 8: Airbus A380 Flying testbed for ZEROe Hydrogen propulsion architecture

4. Novel design and verification means via the "virtual product"

As described, high fidelity testing nowadays not serves any more only for a single and final qualification brick. Instead, it is intended to confirm in an early phase the validity of the design range and calibrate the applicable design tools which can progress the design convergence of the product with significantly improved lead time and cost.

A full virtual product approach will become mandatory to overcome classical sequential and then largely iteratively scheduled design approaches. Finally, a full co-design approach considering simultaneously the impact of all major disciplines will become possible. Furthermore, a virtual end-to-end integrated modeling chain can include parameters usually considered only downstream the development process. Design drivers e.g. from the industrial production system can be mirrored upstream and can be considered as equally valid optimization parameters compared to classical overall aircraft design aspects like, drag, weight or noise. The striking advantage lies in the resulting ability to have full design sets already available ahead of the design convergence into the targeted product. An out of cycle pre-maturation of co-designed solutions becomes possible, which can build a wide foundation for potential product solutions. In its end-to-end parametric modelling widely scalable components can be built and targeted into dedicated product solutions.

Finally, also a distinct design-to-certification approach is necessary within the virtual product chain. Certification rules e.g. for complete novel architectures, such as very high aspect ratio wings or hydrogen storage systems do not yet fully exist and have to be developed in parallel to the maturation of the technologies. A careful consideration of the means of compliance to be provided is therefore necessary. Embedding the parameters of relevance to demonstrate for certifiability right upfront in the virtual design chain ensures staying inside the considered validity range. In turn, an approach to virtual certification is becoming possible.

These novel toolchains need of course to be mandatorily validated upfront any productive application, regarding all aspects of the embedded and connected elements to be modelled in this process chain.

Dedicated high-fidelity physical benchmarks need to ensure the validity of the simulation range, to avoid extensive and iterative testing for intermediate solutions within the core design phase. Different to previous products the optimum solutions for future technology applications may lie outside known and benchmarked areas, i.e. an extrapolation of established solution is limited. Careful selection of the validation cases is therefore necessary.

These considerations are reflected in the recent Airbus lead initiative on Digital Design, Manufacturing & Services (DDMS). The accompanying initiative of the Virtual Product House by DLR [4,5] puts in this conjunction the full representation of a digital thread a specific focus up to the virtual certification competence.

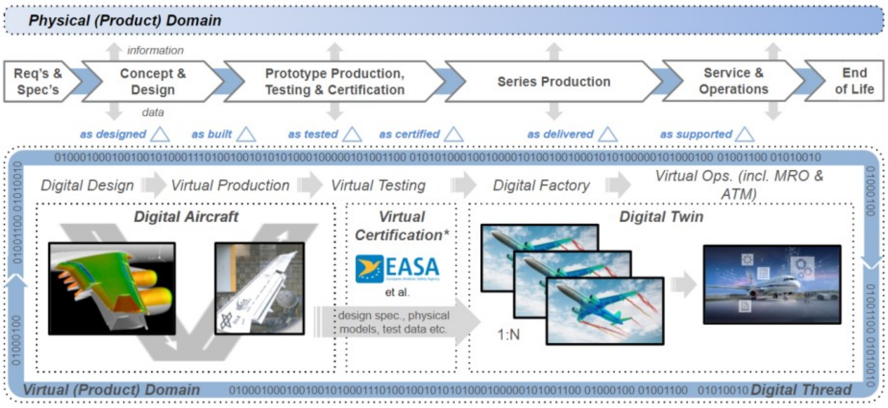

Figure 9: The Virtual Product Approach (Ref: DLR [4])

Besides the buildup of the virtual product chain and its parametrics, the challenge for a reliable and efficient modelling lies in the embedding of simulation tools. Careful selection of similar-fidelity tools is necessary, to avoid one discipline being modelled with high effort in far higher accuracy than needed while another discipline is lacking proper simulation tools. In most disciplines the accessibility and operability of advanced tools has significantly improved, so that full embedded coupling within the process chains, including proper parameter transfer and interfaces is seamless and an automated design range exploration and optimization is possible. An important development to consider is the central use of cross-discipline tools to model multidisciplinary interactions. Examples are CFD-CAA (flight dynamics & acoustics) or CFD-CSM (flight dynamics & structures) integrated modelling functions and related tool-suites. Reliable simulation of nonlinear solution ranges up to the borders of the envelope is of central relevance to avoid unnecessary design margins by “overprotection”. Unsteady modelling, such as for buffet onset, flutter or propeller airframe interaction, becomes a mandatory feature within this simulation capability.

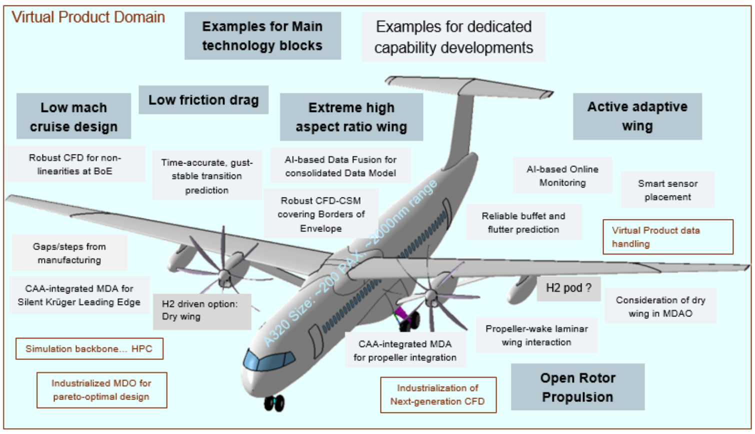

Figure 10: Next generation capabilities required to mature future technology on virtual product level
(Picture shows examples related to the above-mentioned ultraefficient aircraft concept)

5. Outlook: Synergetic overall aircraft level integration

A superior future product will have to collect a set of advanced technologies and bring them in a synergetic combination, which suggests potentially a significant benefit beyond the individual building blocks. A prominent example is the enabling of completely novel hybrid-electric propulsion arrangements by an electric energy supply network, where technology benefits from the more efficient propulsion chain can be leveraged by the configurational benefit of a functionally merged distributed propulsion and flight control architecture.

For this dimension is obvious that integrated demonstration of technologies on overall aircraft configuration level is the mandatory step to take for product application, as technology and configuration level benefits and drawbacks cannot be divided from each other anymore.

Future aircraft product scenarios imply the crucial question, whether a change towards a more non-conventional or even disruptive configuration - such as e.g. the Airbus ZEROe flying wing or the recently exposed Flying V (Figure 11) - is finally a potential alternative way to go. The further development of the classical "tube and wing" configuration inherently yields a high degree of maturity, considering especially the industrial dimension of such a product. Alternatively, disruptive configurations suggest a superior value offer, but so far not even came close to selection for a future product baseline due to associated the huge development risks. The significant challenge for environment friendly aircraft combined with the maturity of certain novel technology bricks may change this trend.

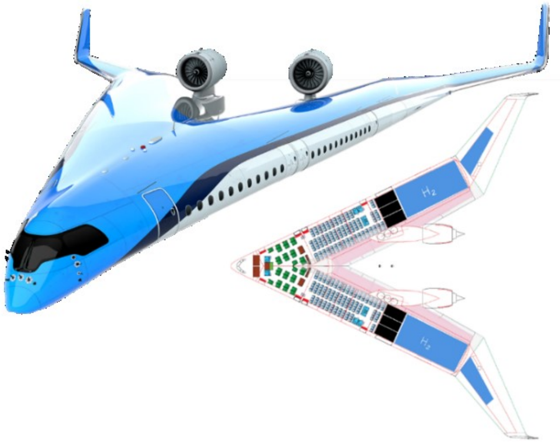

Figure 11: The Flying V concept with hydrogen propulsion (Ref: TU Delft, [6])

Therefore, a concurrent approach of configuration integration and technology development has to be emphasized, in order to mutually target the advancement into a marketable product. Figure 12 shows dedicated examples on the case of Airbus ZEROe product scenarios.

Also, an earlier integrated demonstration on full aircraft product level needs to be considered, to de-risk the technology convergence into a full product. As described, subscale and large scale demonstrators will play an important role, allowing a step into a fully functional integrated architecture, which can be demonstrated in a far earlier phase than classical prototyping and deliver "scalable cornerstones" for a valid design window.

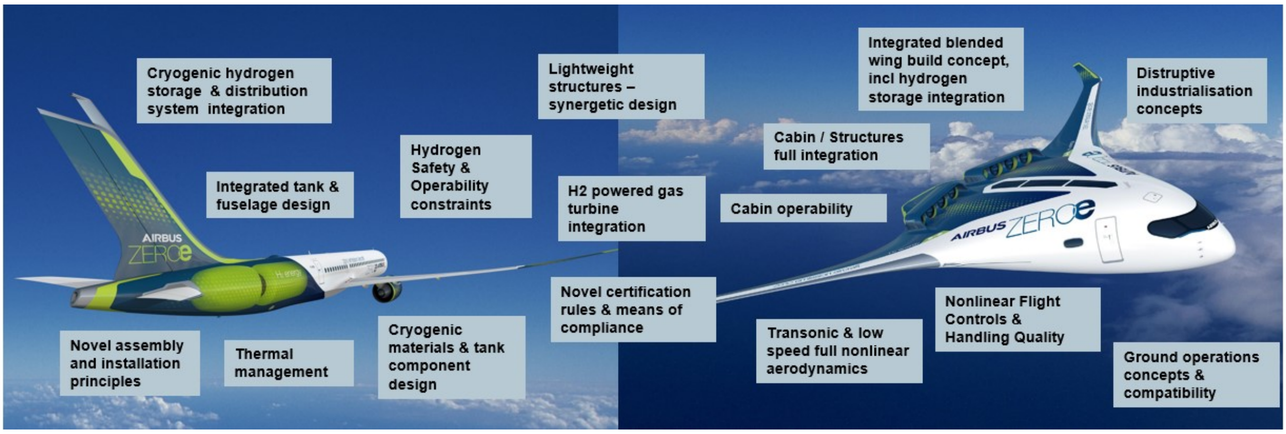

Figure 12: Selected examples on Airbus ZEROe concepts for Aircraft level design integration challenges of technology bricks, requiring a full multidisciplinary end-to-end modelling chain

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