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ORIGINAL ARTICLE

Future aircraft cabins and design thinking: optimisation vs. win-win scenarios

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Abstract With projections indicating an increase in mobility over the next few decades and annual flight departures expected to rise to over 16 billion by 2050, there is a demand for the aviation industry and associated stakeholders to consider new forms of aircraft and technology. Customer requirements are recognized as a key driver in business. The airline is the principal customer for the aircraft manufacture. The passenger is, in turn, the airline's principal customer but they are just one of several stakeholders that include aviation authorities, airport operators, air-traffic control and security agencies. The passenger experience is a key differentiator used by airlines to attract and retain custom and the fuselage that defines the cabin envelope for the in-flight passenger experience and cabin design therefore receives significant attention for new aircraft, service updates and refurbishments. Decision making in design is crucial to arriving at viable and worthwhile cabin formats. Too little innovation will result in an aircraft manufacturer and airlines using its products falling behind its competitors. Too much may result in an over-extension with, for example, use of immature technologies that do not have the necessary reliability for a safety critical industry or sufficient value to justify the development effort. The multiple requirements associated with cabin design, can be viewed as an area

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for optimisation, accepting trade-offs between the various parameters. Good design, however, is often defined as developing a concept that resolves the contradictions and takes the solution towards a win-win scenario. Indeed our understanding and practice of design allows for behaviors that enhance design thinking through divergence and convergence, the use of abductive reasoning, experimentation and systems thinking. This paper explores and defines the challenges of designing the aircraft cabin of the future that will deliver on the multiple requirements using experiences from the A350 XWB and future cabin design concepts. In particular the paper explores the value of implementing design thinking insights in engineering practice and discusses the relative merits of decisions based on optimisation versus win-win scenarios for aircraft cabin design and wider applications in aerospace environments. The increasing densification of technological opportunities and shifting consumer demand coupled with highly complex systems may ultimately challenge our ability to make decisions based on optimisation balances. From an engineering design perspective optimisation tends to preclude certain strategies that deliver high quality results in consumer scenarios whereas win-win solutions may face challenges in complex technical environments.

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1. Introduction

Nearly all projections for future forecasts indicate an increase in mobility over the next few decades. The International Air Transport Association, for example, projects that the number of passenger departures each year globally will rise from 2.3 billion in 2009 to 16 billion by 2050, with Asia providing the major impetus for growth [1] (see also the Global Market Forecast [2]). Such growth, and implied market potential, is driving the aviation industry and associated regulation to consider new forms of aircraft and technology. A key decision for an aircraft concerns the strategic positioning of the airline and therefore what market is it for. This decision consequently has a significant impact on the passenger aircraft design which represents a complex activity. Different markets, whether short-hall, long-haul or area, result in different strategic positioning and business models for the airline or Original Equipment Manufacturer (OEM). If the aircraft is for intercity hops within say Europe, or if the aircraft is to have a range of 8000 nautical miles fulfilling the bulk of requirements for pacific rim cities and North America, then the resulting configuration for the fuselage, wings and engines will be substantially different as a result of passenger numbers, fuel loads and flight path. Engineers are used to considering the trade-offs between the principal parameters such as the number of passengers, range, payload for the range concerned, empty weight, fuel capacity, cruising speed, noise and wing area. There are, however factors that can dominate in the definition of aircraft design [3]. Subsonic jet airliners, for example, tend to have a maximum lift to drag ratio and a maximum Mach number lift to drag ratio product when the lift coefficient is about 0.5. This dictates flight at high altitudes with the altitude increasing as the weight of the fuel decreases during a flight [4].

The airline industry is a highly competitive market. To attract and retain custom the airlines need to differentiate from their competitors. Customer requirements are recognized as a key motivation in business and design with typical value drivers being comfort and the customer experience, services, sustainability, and airline efficiency. In the case of a new purchase, the airline buys or leases the aircraft and operates it becoming the customer for the aircraft manufacturer. The passenger is in turn the airline's principal customer but they are one of several stakeholders that include aviation authorities, airport operators, air traffic control and security agencies. The passenger experience is a key differentiator used by airlines to attract and retain custom. This experience by association covers the period from the first idea to make a journey to buying the ticket, travelling to the airport and getting on board, as well as the in-flight experience, baggage management and passage through towards the final destination. The fuselage defines the cabin envelope for the in-flight passenger experience and cabin design therefore receives significant attention as a key-driver for new aircraft, service updates and refurbishments, while maintaining fleet communality. The aircraft can be viewed as an industrial product while the cabin is a consumer product with different requirements such as shorter lifecycle and greater need for customization and different emphases on value drivers.

Cabin design represents a key precondition for staying competitive.

- In order to stay competitive there is a need for differentiation;
- Differentiation can be achieved by cabin innovations;
- Cabin design innovations are driven by consumer requirements and passenger experience.

Cabin design involves the consideration of many issues, ranging from: emotional aspects of customer perception of aesthetics, quality, personal space, safety and service efficiency; physical aspects such as vibration and sound

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transmission, heating and air-conditioning, odor control and ventilation, artificial and natural lighting; spatial aspects such as circulation and access, seating arrangements and the ergonomics of customers' sitting, sleeping and storage requirements; and constructional aspects such as strength balanced against the need for lightness, and the requirements for flexible layout and maintenance. These aspects act as design drivers for the key areas of comfort and service, sustainability and airline efficiency. Different product life cycles can be assessed to identify the relative advantage between long life and short life recycling for cabin furniture and decor. Consideration of future trends is critical in aircraft design with examples including: more female passengers in leading roles traveling for business reasons, obesity, greying society, rising economic giants, the cultural influence of BRIC countries, all potentially influencing future cabin design and service. Options for cabin layout are multiple from single, twin or triple fuselage, span loader, flying wing, canard, tandem, joined wing. Although many different concepts are available, the issues of the payload, passenger experience, regulation and operations (e.g. short turn-around times increasing legs per day) and the associated business economics serve to define many of the design decisions.

Decision making in design is crucial to arriving at viable and worthwhile cabin formats. Too little innovation will result in an aircraft manufacturer and airlines using its products falling behind its competitors, possibly with already antiquated technologies at the point of release. Too much may result in an over-extension, for example the use of immature technologies that do not have the necessary reliability for a safety critical industry. In a fast paced technology sector, adaptability to projected new technologies is important. The multiple requirements associated with cabin design, can be viewed as an area for optimisation, accepting trade-offs between the various parameters. Good design, however, is often defined as developing a concept that resolves the contradictions and takes the solution towards a win-win scenario. Indeed our understanding and practice of design allows for behaviors that enhance design thinking through periods of divergence and convergence, the use of abductive reasoning, experimentation and systems thinking. This paper explores the challenges of designing the aircraft cabin of the future that will deliver on these multiple requirements. In particular the paper explores the value of implementing design thinking insights in engineering practice and discusses the relative merits of decisions based on optimisation versus win-win scenarios for aircraft cabin design and wider applications in aerospace environments. The increasing densification of technological opportunities in aerospace and shifting consumer demand coupled with highly complex systems may ultimately challenge our ability to make decisions based on optimisation balances. From design and associated decision making perspectives, optimisation tends to preclude strategies that deliver high quality results in consumer scenarios whereas win-win solutions may present challenges in complex technical environments. The merits and disadvantages of these approaches are compared and articulated further in Sections 2–4.

2. Fuselage and cabin design drivers

Many areas of industrial design are driven by consumer demands where industry, researchers and designers have developed tools to respond accordingly. A consumer centric design approach can be used with consideration of:

(1) User/market;
(2) Airline;
(3) Aircraft;
(4) Technology.

Design for all or universal design, focus groups, concept models and extreme user scenarios are all examples of creative approaches that provide a feedback loop from users to creators to ensure that product offerings are fit for purpose and meet the exacting standards of the increasingly well informed and selective contemporary consumers. Design testing with consumers can be performed in a very early stage using virtual reality and hardware mock-ups.

Traditional aircraft interiors were driven by optimisation methods focused largely on functional criteria with little value given to consumer quality. The 1950s saw an explosion in passenger transport and an emphasis on the quality of the travelling environment where top car and aircraft interiors were roughly comparable (epitomized by Cadillac and PanAm). The pace of change in the aircraft industry has slowed and now there appears to be a significant gap between the two experiences.

The automotive industry is a good example in a related high investment, safety critical transportation industry where strong mechanisms exist between consumers and designers for developing new products that will have a high chance of consumer acceptance replayed as successful sales. When direct comparisons are made with say the latest Audi, BMW, Lexus or concept car interiors, significant differences can be found with current aircraft interiors as a result of differing design approaches. Both the aircraft and automotive industries are considered to be ‘lock-out’. In other words, new and competing technologies can only be incorporated into the product with the express desire of the manufacturer. This contrasts to the consumer product industry where competing online brands and digital technologies are now challenging the very foundations and business models of traditional consumer product manufacturing in the computer and communications industries for laptops and smart phones etc. The concept of a ‘lock-out’ industry exists for good reason in assuring the safety and reliability of essential strategic global transportation systems where a piece of badly written of malicious code could have disastrous consequences. However the automotive industry is now embracing strategic partnerships with some of these brands including Microsoft, Google and Nokia,

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motivated by the increasing demands of offering enhanced passenger and driver experiences and engagement models in a highly competitive marketplace.

A useful comparison may for example be made between premium automotive brands and first and premium class airline interiors and similarly between low-cost automobile brands and low-cost carriers. The aerospace industry however has a number of unique factors and challenges in adopting this model:

- Brand layers or consumer brand distance: Passengers do not buy planes. Their first brand experience will be through the airline or third party website like Expedia or lastminute.com and check-in desks. Many passengers may actually be unaware of the model or type of aeroplane they are flying in until they board, if they become aware at all. One cabin design needs to fulfil the requirements of many different airline brands. Airlines are interested in fleet communality. The cabin design language needs to communicate and deliver both the brand values of the Original Equipment Manufacturer (OEM) while at the same time providing a platform for any airline to express their own brand identity
- Airline and fit-out: Many passengers assume that the interior is designed and installed by the aircraft manufacturer when in fact it (especially seats and seat configuration) is commissioned by the airline themselves and often retro-fitted or refitted after delivery by a third party contractor, although some parts may remain in the cabin significantly longer.
- High performance: Aircraft cabins are designed and manufactured to exacting safety critical standards where weight saving and performance to extreme accelerations upwards of 16 g are mandatory. These standards are both a challenge and motivation for innovation.

The challenge for cabin designers is how to leverage user responsive design methods in a safety critical industry using optimisation methods and where consumer feedback is relayed though clients. New cabin concept designs have to appeal primarily to aircraft buying clients but also importantly to the flying public who are a key element in driving design function and satisfaction [5]. Although the passengers are obviously the key user group their stake in the business model involves paying airlines and not commissioning aircraft and as a result their voice has a much lower influence in the design process. The OEM, however, must anticipate the needs of new product or service requirements that could best be sold to the passenger a few years ahead of any airline perspective or create an open platform enabling future services and upgrades. For the A350 XWB for example, Airbus has made extensive use of digital and hardware mock-ups enabling exploration of future travel scenarios to identify passenger needs and then position technology accordingly. The anticipated passenger demands/needs were based on trend research and scenario work (Chrysalis Mockup for the A350 XWB).

Demand for energy efficiency requirements in manufacturing, competition from land based ultra-high speed rail networks, new engagement models for automotive industries and the emerging space tourism market all drive user experience demands to new levels. Responding to these challenges will require radical new production systems to create the next generations of products and systems. Airbus for example, is already developing additive layer manufacturing technologies and studying new fuselage paradigms. Such technologies make it easier to customise cabin components, with lightweight and integrative design using sophisticated design solutions. The emergence of radical new production platforms has the potential to revolutionise the industry but at the same time can allow disruptive market innovations that could rapidly capture market share.

3. Design optimisation

Inevitably there are conflicts between the diversity of requirements driven by the stakeholders. Optimisation is the process of repetitively refining a set of often-conflicting criteria to achieve the best compromise. In the case of a transportation system, size, manoeuvrability, cost, aesthetic appeal, ease of use, stability, safety and speed are not necessarily all in accordance with each other. Priorities can change within the lifetime of a product and vary within markets and cultures. Cost minimisation may call for compromises on material usage and manufacturing methods. These considerations form part of the optimisation of the product producing the best or most acceptable compromise between the desired criteria.

A traditional engineering design process comprises a series of often sequential steps, beginning with defined requirements or an opportunity and proceeding through ideation, synthesis, analysis and optimisation, to production. This process can be controlled by a series of gate reviews in coordination with the stakeholders and the process can be iterative with phases being revisited when re-work is recognized as necessary. This type of process can lead to bottlenecks in activity and a tendency to stick to a particular sub-optimal solution as so much time and effort has already been allocated to it. Nevertheless such an approach makes continuous improvement of this long life product well-organised and possible as functionalities and systems are arranged into ATA-chapters.

Problem-solution oriented design processes simplify issues to solvable problem sets by reducing uncertainty, comparing problems to similar previously solved problems and extracting issues from the full complexity of their context. Removing contextual richness and hence innovation potential is driven by 'what we know how to solve and make' rather than 'new things we want to make with new solutions'. Simplified, this contrast illustrates a technology driven innovation versus a design driven innovation

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approach. Design driven innovation approaches invariably include human desires and responses at their core level and are prime operators in the win-win design scenario.

The range of optimisation tools used in design is reviewed by [6]. Multi-disciplinary design optimisation (MDO), for example, combines tools and approaches from a number of disciplines in order to tackle the refinement of a set of parameters for a given problem area in order to deliver the best compromise between those parameters and has been widely applied in aerospace applications. A key characteristic of multi-disciplinary design optimisation (MDO) is that the solution is better than that obtained by optimizing each of the parameters sequentially. The approach is resource intensive in terms of computational power, however the Moore's law enhancement of processing means that this is not a hindrance to application of the approach. Optimisation approaches and numerical strategies typically employed have included decomposition, approximation, evolutionary and mimetic algorithms, response surface methodologies, reliability and multi-objective. The METUS methodology [7], for example, has been used in Airbus development programs to help provide a holistic approach to product development, covering the phases of conception and optimisation of product architecture, visualization and integration of partners in the supply chain.

MDO can be considered to be a methodology for the design of an engineering system that exploits the synergies between interacting parameters. The principle of MDO is that it provides the collection of tools and methods that enables and permits the trade-off between different disciplines inherent in design. Proponents of MDO suggest that this provides the justification for its application at an early stage in a product development program [8].

Ideally, an MDO environment should permit the definition of the brief and specification constraints for all the various stakeholders [9]. This is typically achieved using a single parametric model for the whole system facilitating effective communication between the different stakeholders. MDO offers the potential for the interactions between subsystems and systems to be explored from an early stage in the design process by a number of stakeholders. The purpose is to find the minima for the cost functions and reach an optimal solution for the holistic system. A core challenge in the design of modern aircraft with consideration of multiple parameters is that some the parameters can appear ‘soft’ especially when designing an aircraft 10 or more years ahead of its launch. Experience has shown that the prioritization of parameters is very complex especially when all stakeholders are involved and the emphasis placed on the parameters requires advanced skills in communication and decision making. This approach potentially has benefits as a result of the evolutionary steps of improvement or adaptations to new environments during the lifecycle, up to 30 years, as a parametric model can indicate immediately impacts or the effort for adaptations in the design and thus the system. Use of MDO in its full potential implicates a paradigm change of working processes and requires additional skills and education.

The introduction of aluminum has had a significant influence on the aircraft industry and the development of modeling tools. Within a short period of time aircraft design and the aircraft industry was transformed in terms of range, speed, passenger numbers and comfort. Indeed the introduction of aluminum marked the origins for today's aircraft architecture with its optimized stiffened skin structure [10,11]. The challenges associated with the engineering provided much of the impetus for the development and use of optimisation tools.

The scope of applicability of optimisation has steadily increased from consideration of minimum weight for structural integrity to consideration of aeroelasticity, avionics and performance parameters. Examples of the application of MDO within the aerospace sector abound [12,13], F-16 [14], F-22 [15], wings and efficiency [16–18], blended wing [19], cost [20], preliminary design [21]. Efficient multipoint aerodynamic design optimisation is considered in [22–24]. Consideration of aspects such as the passenger thermal and acoustic environment have tended to be considered sequentially in the design process and if optimisation is used this is applied to a subsystem which is constrained within a geometric envelope that has defined by a ‘higher-level’ optimisation. The definition of the hierarchy of priorities within a project is a key attribute of any product or system development program and subject to the process of decision management and decision taking which can have a fundamental impact on the scope and therefore effectiveness of any optimisation attempt [25,26].

Design has many different meanings depending on domain and viewpoint. Research on design thinking, the set of mental processes that enable design and are prevalent in design business and practice, has identified a series of distinct characteristics that occur during the design process. Design thinking has been characterized as a conversation with the application or issue [27]. The designer through a medium such as sketches enters into a dialogue of interactions with an action determining a response and judgment as to whether the direction is profitable and worth pursuing. Processes such as drawing help in organizing the material and consideration of the multitude of factors. As a result of organizing material, concepts can be developed that address the series of relevant factors identified as important at the specific stage of design concerned. This is applied with internal cabin design concepts, demonstrators and partially also with public concept cabins. Advanced design studies combine scenario process based understanding with trends, passenger surveys before matching this design with potential R&T projects. The result can be tested with customers or potential passengers in hardware demonstrators or a virtual reality environment. A characteristic of design thinking is its solution focus, with problem scoping rather than detailed problem specification. This approach is more pro-active and tends to provide a more holistic product while the optimisation approach primarily has a focus on specified problems which leads to a passive form of creation. In a project of development and certification to

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deliver a new product lasting a few years this could cost precious time. Apple, for example, famously created its market and did not focus only on a function to play mp3s as did many of its followers.

Abductive thinking is a key ingredient, if not a core component of design thinking. Abductive thinking concerns the mental process of proposing something that could be ‘true’ or right or useful. Abductive thinking is influenced by incentive and in the case of a designer by the value associated with the outcome. One could consider high level creative thinkers as having the ability to imagine futures that divert from the predictable, leading to new current actions that develop novel solutions and approaches. This reverse model initiated by future projection contrasts with the widely accepted linear-progressive creative model of research-concept-design-develop-make. Characteristics of design thinking include: synthesizing an intent and abductive reasoning, experimentation, exploring combinations, coping with ambiguity, a systems approach, gaining insights from data and the application of skills. In the context of industry, consideration of Net Present Value and associated analysis can be used to provide estimates for economic value.

4. Design influences

A wide range of factors influence design decisions. Some of the influences can be quantified and can therefore be defined as a parameter suitable for optimisation. At the early stage in the development of a product or system, a wide range of influences will be relevant such as what direction and form the project should take. In this phase it may be difficult to quantify constraints and therefore define objective functions. As a result connections to consumers that drive change and the motivation for consumers to engage with airlines may be underexploited.

In 2010, the Royal College of Art (RCA) and Imperial College London's dual masters in Innovation Design Engineering (IDE) [28] collaborated with Airbus to explore new design concepts. The project formed part of the commercial client activities of the program aimed at introducing students to top global design scenarios with leading edge manufacturers. Previous projects have been conducted in partnership with the BBC, Elmar, Ford, Guzzini, Hutchison Whampoa, LG, Nokia, Philips, Pramac, RIM, Sony, Swarovski, Thales, Alenia, Unilever, and Vodafone. The initial four week intensive program of work began with a client briefing from Airbus and continued with tutoring from IDE staff alongside Airbus through tutorials and project reviews culminating in a final critique of conceptual ideas for new cabin designs. A final project was selected and further refined in an eight week phase 2 project combining design and engineering expertise from students and academics from the RCA and Imperial College.

During the collaboration, a number of interesting factors pertinent to this discussion and comparison of design methods were observed: In the final presentation some of the student groups ‘acted’ their concepts through the eyes of passengers, as suggested in the original briefing, using their ideas. Designers used this immersive method to see and create from inside the mind-set and experience of users. The designs were driven essentially via a top-down experience driven model where the quality and ambience of the cabin became the main driver and where technology became the enabler in the form of props on a theatre set. The creative groups were composed of masters students from three different disciplines comprising Innovation Design Engineering, Vehicle Design and Textiles working in ten mixed groups of four students each. In addition to the three

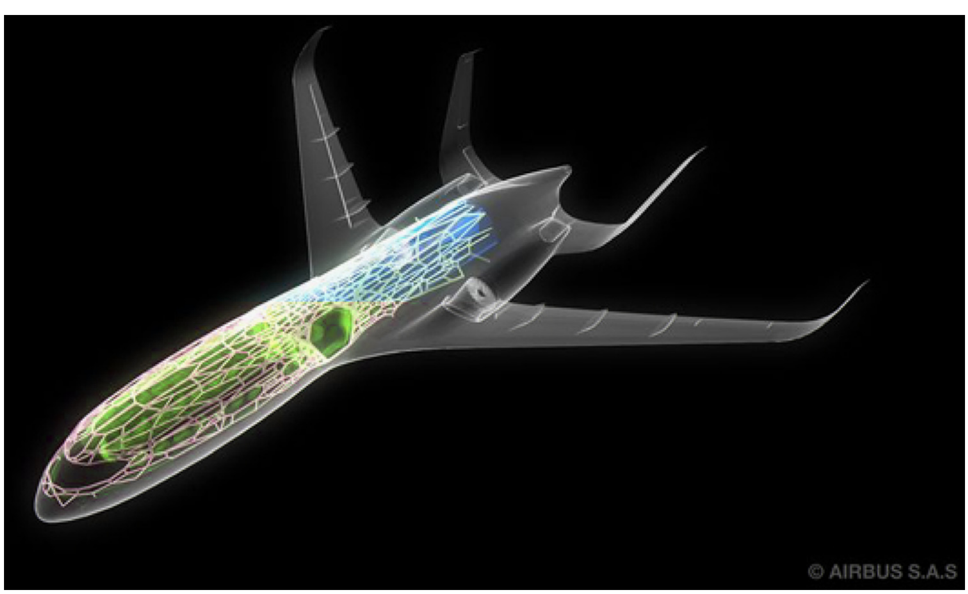

Figure 1 Future cabin design. Image courtesy of Airbus.

departments student backgrounds and cultures were increasingly mixed where in the case of IDE alone the students were from 12 different disciplines and 14 countries from a wide global spread. The diversity of groups and disciplines allowed not only diverse disciplinary skills to be collectively employed, but also provided a rich tapestry of cultures that were drawn upon to create new and innovative experience designs. Several groups 'escaped from the boundaries of the briefing creatively' by either challenging the design brief of taking on larger challenges associated with the project core. One group in particular sought to design not only the cabin interior but the entire aircraft fuselage arguing that the two were so interconnected that it would be impossible to design one without the other. The group proposed a novel combination of biomimetic structures derived from finite element analysis of existing forces that were fed into Voronoi geometric negotiation software. The concept implicated a new way of using the cabin

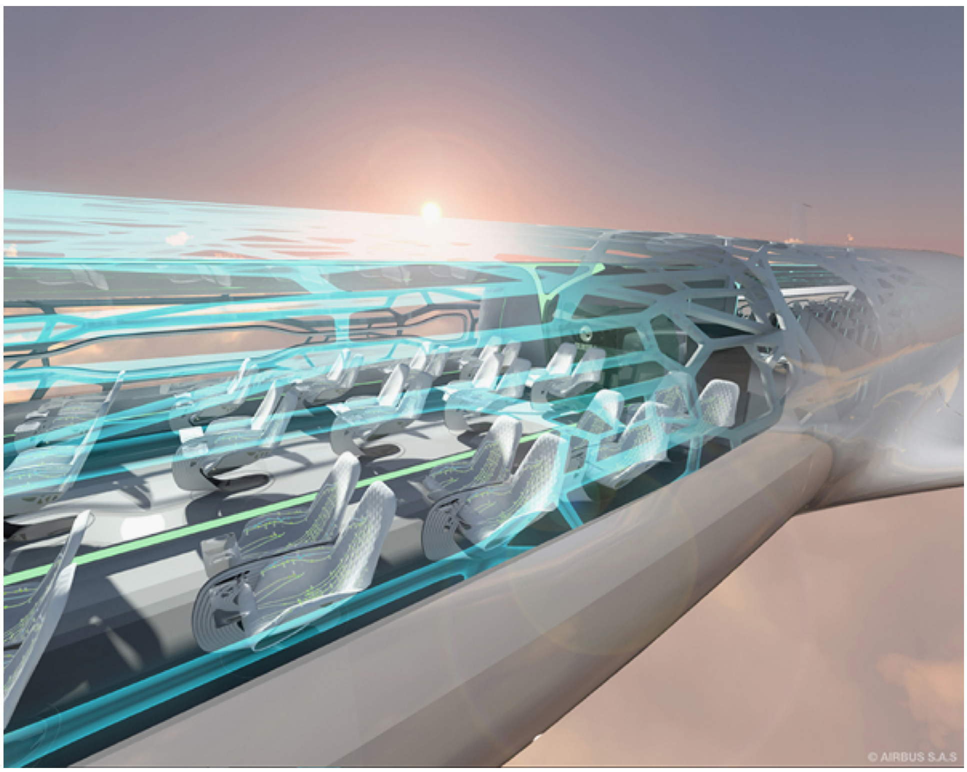

Figure 2 Future cabin design. Image courtesy of Airbus.

Figure 3 Future cabin design. Image courtesy of Airbus.

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envelope three-dimensionally where structural parameters were matched with defined passenger space envelopes. This solution was considered sufficiently interesting to merit further exploration and development by both parties in the phase 2 project.

Examples of the Airbus Concept Cabin rolled out in 2011 show an approach where future passenger needs derived from extensive social-demographic and economical trend analysis are translated into cabin touch points (see Figure 1 to Figure 4 [29]). Instead of maintaining traditional cabin classes those needs have been placed in an emotional value driven vitalizing zone whereas functional values have been placed in the smart technology zone. In between is an interaction zone providing possibilities for airlines to use the cabin as a flexible market place. All zones where aligned with long-term technology roadmaps to figure out possibilities and potential for realisation in order to use technology as a useful enabler. The concept was inspired by bionic principles, from neuronal network, a cabin membrane to a stiffening structure. The future customer and his needs have been in the very heart of the concept.

Of interest the biomimetic approach has also been demonstrated in the Airbus Utopium Project were large scale FEM topology optimisation manufactured in Additive Layer Manufacturing has been investigated. Ultra strong materials including carbon fibre nanotubes were considered to enable large scale multifunctional components. More short term projects such as the bionic bracket design by Airbus

Figure 4 Future cabin design. Image courtesy of Airbus.

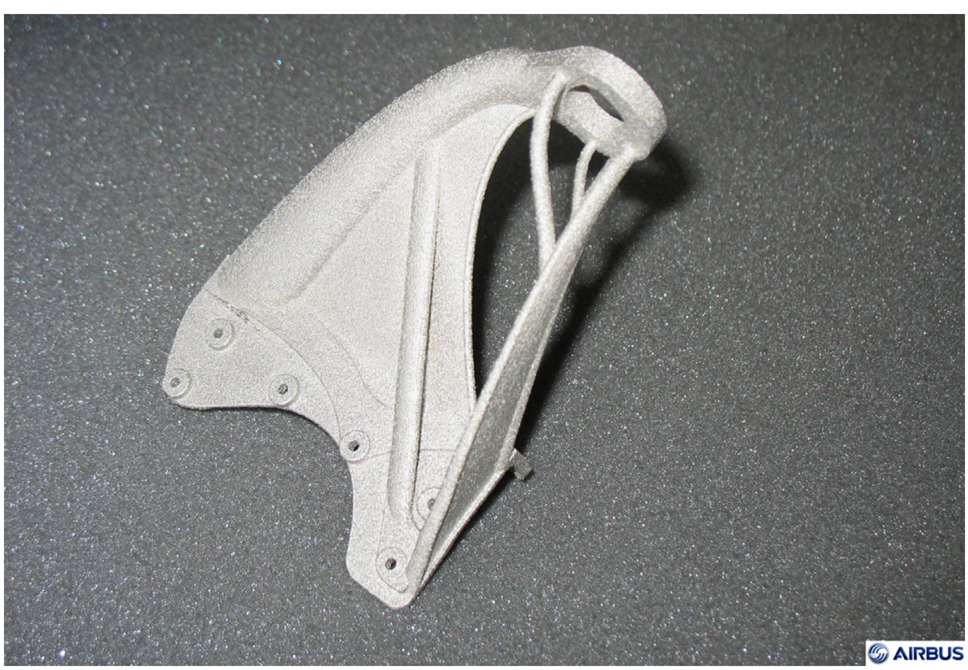

Figure 5 Bionic bracket design. Image courtesy of Airbus.

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and the Technical University Hamburg Harburg shows high potential of revolutionizing cabin design, Figure 5.

The moves by Airbus to consider a full double decker as embodied by the A380 and the high use of composites by Boeing and Airbus in the 787 and A350 XWB respectively can be considered to be visionary. For a multitude of reasons relating to risk and cost as well as the number of key OEMs, e.g. Boeing, Airbus, Embraer, the scope and pace of innovation is inevitably limited in aerospace in comparison to some domains. Whether the user experience and service delivery being provided are meeting the requirements expected is questionable.

In a passenger and airline driven economy with competition from other forms of transport and the desire for disruptive two aspects are crucial:

(1) That customer (passenger) satisfaction becomes the key driver;

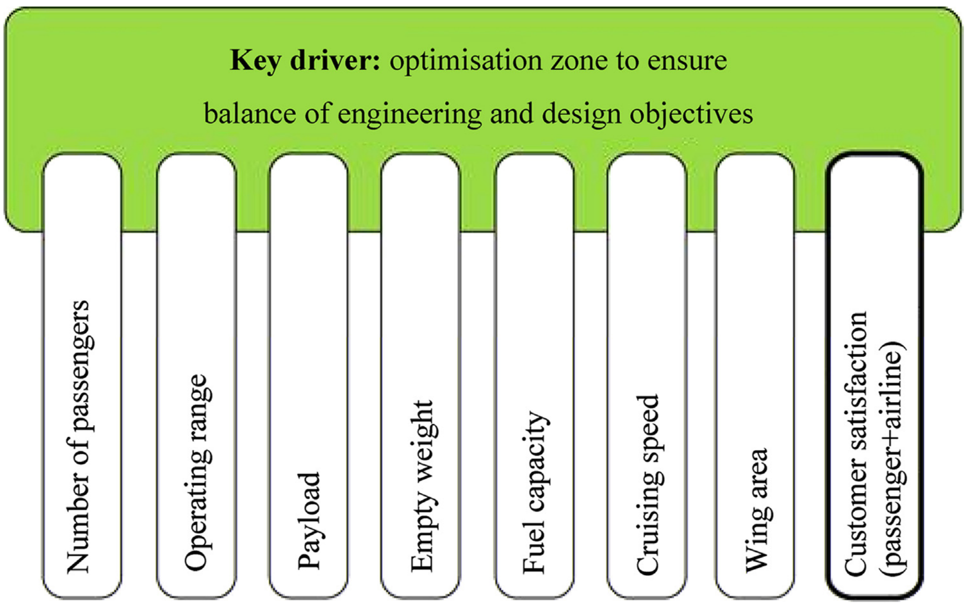

Figure 6 Parameter optimisation.

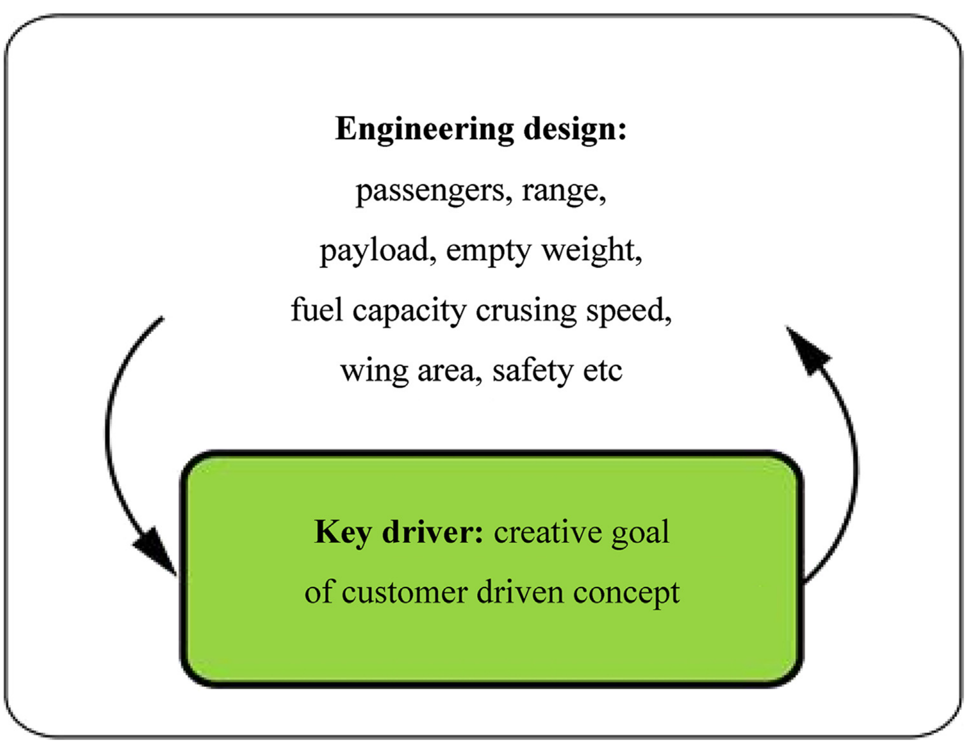

Figure 7 Characteristics of the creative goal using win-win design scenarios.

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Table 1 Optimisation vs. win-win design process, risks and key operators.

Key operators	Optimisation	Win-win
Innovation	Technology driven	Human centred
Technology	Key driver	Responds to human/design/economic requirements
Human centered	Optimized alongside other attributes	Key driver
Safety critical	Primary	Critical, in context with win-win payoffs
Process development	Linear iterative	Elements of non-linearity and recursive loops
Risks	**Optimisation**	**Win-win**
Safety	Well adapted through tried and tested processes	Non-linearity and recursive loops increase complexity; processes unlikely to be uniform
Market drivers	Vulnerable to disruptive market innovations	Generator of disruptive market innovations
User/consumer	Is included in the process as an optimisation and likely for the experience to be reduced or compromised	Drives the creative process via 'best possible' user scenarios

(2) That engineering design collaborates in a reciprocal relationship testing and being challenged to deliver new innovations to meet a customer driven concept model.

Figure 6, Figure 7 and Table 1 illustrate a comparison between optimisation and win-win based design scenarios. The green zone illustrates the balancing of decisions and needs. The black outline delineates user drivers. The win-win scenario, illustrated in Figure 7 unites both of these.

5. Conclusions

The airline industry is a highly competitive market that needs to attract and retain customers in order to differentiate from internal and external competitors. Customer requirements are recognised as a key motivation in business development where cabin design represents a key precondition for remaining competitive. Innovations are driven by consumer requirements and passenger experience where cabin design represents a complex design challenge with multiple systems, stakeholders and agents. This paper has used experiences from the A350 XWB and future cabin design projects to explore the issues in the use of design thinking combined with optimisation approaches in order to deliver a win-win scenario. The principal outcomes for cabin design are as follows.

- Lock-out industries are increasingly being challenged by new emerging consumer demands and customer centric models of engagement from other industries and pressure from digital communication and entertainment platforms.
- Forward thinking manufacturers need to be aware of the emerging threats and opportunities in their markets and use design thinking to respond to consumer demand.
- The design parameter choice cannot be left solely to the OEM but needs to engage the full range of stakeholders via a user experience driven scenario.
- Design methods and sophistication has advanced sufficiently such that immediate impact of affected systems is now possible at the conceptual stage.
- A dynamic approach using abductive thinking in combination with advanced engineering analysis such as MDO needs to be embraced for cabin design. However challenges remain in how to identify and reliably transform soft user requirements that are subject to vagaries and interpretation difficulties into reliable data.
- Win-win design thinking is now proposed to increase the envelope of operation and facilitate a customer driven approach.

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References

[1] IATA state of the air transport industry 2010, URL: ⟨www.iata.org/pressroom/speeches/pages/2010-06-07-01.aspx⟩ [cited 27 June 2012].

[2] Global Market Forecast 2011-2030, Airbus, URL: ⟨www.airbus.com/company/market/forecast/⟩ [cited 27 June 2012].

[3] P. Brooker, Civil aircraft design priorities: air quality? climate change? noise?, Aeronautical Journal 110 (1110) (2006) 517–532.

[4] N. Cumpsty, Jet Propulsion: A Simple Guide to the Aerodynamic and Thermodynamic Design and Performance of Jet Engines, Cambridge University Press, London, 2003.

[5] P. Vink, K. Brauer, in: Aircraft Interior Comfort and Design (Ergonomics Design Management: Theory and Applications), First ed., CRC Press, Boca Raton, 2011.

[6] R. Roy, S. Hinduja, R. Teti, Recent advances in engineering design optimisation: challenges and future trends, CIRP Annals - Manufacturing Technology 57 (2) (2008) 697–715.

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[7] METUS, URL: ⟨http://www.id-consult.com/en/metus-software/⟩ [cited 23 June 2012].
[8] J. Sobieszczanski-Sobieski, J.-F.M. Barthelemy, G.L. Giles, Aerospace engineering design by systematic decomposition and multilevel optimisation, in: 14th Congress of the International Council of the Aeronautical Sciences (ICAS), 1984.
[9] N. Kroll, D. Schwamborn, K. Becker, H. Rieger, F. Thiele, (Eds.), MEGADESIGN and MegaOpt - German initiatives for aerodynamic simulation and optimisation in aircraft design: results of the closing symposium of the MEGADESIGN and MegaOpt projects, Springer, 2009.
[10] A. Beukers, M.J.L. Van Tooren, Th. De Jong, Multi-disciplinary design philosophy for aircraft fuselages, Part I, Applied Composite Materials 12 (1) (2005) 3–11.
[11] Th. De Jong, A. Beukers, M.J.L. Van Tooren, Two simple design problems, which illustrate the multi-disciplinary concept, Part II, Applied Composite Materials 12 (1) (2005) 13–19.
[12] AGARD-R-784, Integrated design analysis and optimisation of aircraft structures, Advisory Group for Aerospace Research and Development (North Atlantic Treaty Organisation), 1992.
[13] White paper on current state of the art, AIAA Technical Committee on MDO, AIAA, 1991.
[14] M.H. Love, Multidisciplinary design practices from the F-16 agile falcon, in: 7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimisation, 1998, AIAA 98-4704.
[15] N. Radovcich, D. Layton, The F-22 structural aeroelastic design process with MDO examples, in: 7th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimisation, 1998.
[16] W.J. Vankan, E. Kesseler, M. Laban, Multi-objective optimisation of aircraft range and fuel consumption, National Aerospace Laboratory NLR, NLR-TP-2007-522, 2007.
[17] E. Kesseler, W.J. Vankan, Multidisciplinary design analysis and multi-objective optimisation applied to aircraft wing, National Aerospace Laboratory NLR, NLR-TP-2006-748, 2006.
[18] E. Kesseler, M. Laban, W.J. Vankan, Consistent models for integrated multi-disciplinary aircraft wing design, in: International Conference on Non-Linear Problems in Aerospace and Aeronautics, Budapest, Hungary, 2006, NLR-TP-2006-495.
[19] A. Velicki, P. Thrash, Blended wing body structural concept development, Aeronautical Journal 114 (1158) (2010) 513–519.
[20] G.C. Bower, I.M. Kroo, Multi-objective aircraft optimisation for minimum cost and emissions over specific route networks, in: 26th International Congress of the Aeronautical Sciences, 2008.
[21] A. Gazaix, P. Gendre, E. Chaput, C. Blondeau, G. Carrier, P. Schmollgruber, J. Brezillon, T. Kier, Investigation of multidisciplinary optimisation for aircraft preliminary design, SAE Technical Paper 2011-01-2761, 2011.
[22] A.J. Keane, J.P. Scanlan, Design search and optimisation in aerospace engineering, Philosophical Transactions of the Royal Society 365 (1859) (2007) 2501–2529.
[23] D.J.J. Toal, A.J. Keane, Efficient multipoint aerodynamic design optimisation via cokriging, Journal of Aircraft 48 (5) (2011) 1685–1695.
[24] I. Voutchkov, A.J. Keane, M. Benison, P. Haynes, T. Stocks, Fast design optimisation of jet engine structural mass and specific fuel consumption, Journal of Aerospace Engineering 225 (10) (2011) 1165–1173.
[25] M. Aurisicchio, R. Bracewell, Engineering design by integrated diagrams, in: Proceedings of the 17th International Conference on Engineering Design, ICED 09, Stanford, USA, 2009.
[26] N. Eng, M. Aurisicchio, R. Bracewell, G. Armstong, Mapping for design thinking support in industry, in: Proceedings of the ASME 2012 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, 2012, Paper DETC2012-70959.
[27] D.A. Schön, The Reflective Practitioner: How Professionals Think in Action, Basic Books, New York, 1983.
[28] A. Hall, P. Childs, Innovation design engineering: Non-linear progressive education for diverse intakes, in: International Conference on Engineering and Product Design Education, Brighton, United Kingdom, 10-11 September 2009, pp. 312-317.
[29] Airbus, Airbus presents a panoramic view of 2050, URL: ⟨www.airbus.com/presscentre/pressreleases/press-release-detail/detail/airbus-presents-a-panoramic-view-of-2050/⟩ [cited 29 March 2012].

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