Long-Term Development of the Field of Aeronautics

– Economy and Ecology in Harmony –

A Memorandum of the Aeronautische Senioren München

Munich, Germany, November 2012

Foreword of the English Version

In 2012 the Aeronautische Senioren München (ASM) authored the memorandum "Langfristige Entwicklung der zivilen Luftfahrtbranche – Ökonomie and Ökologie im Einklang". This memorandum found some positive response. Although the memorandum concentrates on the situation in Germany, it certainly addresses topics of interest for the general field of aeronautics. This was expressed by several readers. Therefore this English version was produced. In the past two years of course the situation changed regarding some of the addressed topics. It was decided however to keep the contents of the original German version untouched. This regards also the name EADS and that of its departments. We hope that the English version of the memorandum also finds a positive reception.

The ASM

Munich, June 2014

Foreword

The German field of aeronautics, in the following understood as the aggregate of the aircraft industry, the aeronautical research outside and inside the universities, and the academia, is recognised as potent and successful. The prime manufacturing companies (airframe, propulsion) and the tier-one suppliers (subsystems) are mostly acting in a European context, whereas their market is a world wide one. There are close links between all European research institutions. Activities in research and development are performed by all partners in national and international, but predominantly European consortia.

With this memorandum the Aeronautische Senioren München (ASM, Aeronautical Seniors Munich) would like to make suggestions and recommendations for developments that from their point of view are deemed necessary to reinforce the field of aeronautics itself economically, while taking into account the increasing ecologic constraints and the worldwide competition.

ASM is a loose community of former engineers, researchers, university professors and aircraft pilots from the field and from aircraft operators. They consider themselves as independent experts, who cover wide areas of the field.

Their suggestions and recommendations primarily refer to civil transport aircraft for passengers and freight, and also to helicopters, STOL and VTOL aircraft. General aviation and military aircraft are not within the scope of the considerations.

This memorandum is addressed to the industrial partners, the aviation research, to the universities, to the sponsoring institutions as well as to all political institutions (members of parliament, political parties, ministries), who are concerned with issues of the field of aeronautics.

The memorandum arose in the years 2011 and 2012 out of a series of presentations and brainstorming sessions within ASM. The document includes an executive summary, followed by the memorandum from page 7 on.

Additional information concerning the memorandum as well as the electronic version of this document can be requested from the contact person
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Munich, November 2012

Executive Summary

The German field of aeronautics is a potent and successful field. The Aeronautical Seniors München (ASM) give suggestions and recommendations for developments, which from their point of view are necessary to strengthen the field with respect to the upcoming economic and ecologic challenges. These suggestions and recommendations essentially refer to civil transport aircraft, i.e., passenger carriers and freighters. However, they hold for every other aircraft class, too. In the case of the military aircraft area the preservation of advanced design capability is seen as a matter of urgency.

A quantitative comparison of the traffic carrier aircraft with railway and road traffic carriers reveals interesting results with respect to land consumption, primary energy demand, cost structures and environment problems. Air traffic by far cannot be seen so negative as it is presented mostly. On the contrary, it has some advantages when compared with the other traffic carriers, which nowadays is not adequately communicated. Nevertheless, there is a range of very big challenges, which the field of aeronautics has to master.

The consideration of some basic interdependencies with regard to studies of unconventional aircraft configurations leads to the statement, that the current configuration of aircraft of the Airbus type is probably the optimum one (admittedly different for short, medium and long range aircraft). This configuration is regarded as imperative to be developed further on, with due consideration of economic and ecologic aspects. This does not exclude the implementation of some unconventional elements into new configurations.

For future product definition it is mandatory to develop economic efficiency measures. Very large potentials, which by far are not exploited, can be identified in the methodology of aircraft definition and development. The main problem is envisaged in the today quantitatively and qualitatively insufficient description of the physical properties and functions of the aircraft in its early definition phases. This is critical, because in these phases the later operational and life cycle costs are fixed with a far-reaching impact.

New approaches based on information technologies can produce relief as well as the employment of high-quality computational design methods ("Virtual Product"), which allow an integral description of the product. The latter is true collectively for the aircraft definition and development, which still is oriented essentially towards Cayley's design paradigm. That assumes a weak interdependency between different subsystems and different functions. When the linkages are stronger, the use of the addressed procedures – which take this into account – becomes mandatory.

Germany nowadays has almost lost the industrial capability to develop large aircraft by its own. The German participation in products of EADS is only partial. It is recommended to perform in Germany the definition and development of, for instance, an A320 successor with the described advanced way of procedures. This would result in positive effects for Airbus/EADS. These are desirable impulses in the areas of economy, research and education in Germany. This would also strengthen the internal competition at Airbus, thus fostering innovation. Moreover, the establishment of a long lasting programme would create an incentive for excellent young German engineers to enter the field of aeronautics and to stay there.

Additional recommendations concern aerodynamics, advanced materials and manufacturing technology – where the potentials of carbon fibre composites must be exploited much stronger than until now – and also other disciplines. In addition it is recommended to reconsider the potential of large aircraft for freight transport, as well as that of VTOL aircraft for countries with a weakly developed traffic infrastructure.

General recommendations aiming at improving the competitiveness of the aircraft industry with respect to the upcoming challenges deal with the organisational structures in industry, research and education. The current industrial organisations are structured as cost centres of technical disciplines. Education at universities and research institutes are discipline-oriented too. It is recommended to give stimuli to overcome the borders between the disciplines wherever it seems to be necessary. In addition much more attention should be given to the level of technical expertise of the managers in charge of product definition and development. Here a change of thinking is recommended.

Globally, the sales success of Airbus confirms that the aircraft industry today is economically successful. However, with respect to the upcoming competition situation and the economical and ecological challenges, the current approaches in definition and development of products, the organisational structures, performance paradigms and also the knowledge transfer must partially be questioned. All this has to be improved by all means.

The Memorandum

1 Introduction

The memorandum with its suggestions and recommendations primarily refers to civil transport aircraft for passengers and cargo as well as to helicopters and STOL and VTOL aircraft. Sports aircraft, general aviation and military aircraft are not in the focus of the considerations. However all suggestions and recommendations are valid for them too.

The memorandum is structured in separate sections. In Section 2 the rating of the aircraft industry in Germany, in Section 3 its position in the international competition situation are discussed. The aircraft in comparison with other surface means of transportation is considered in Section 4. Section 5 is dedicated to the description of some basic relationships that sometimes are neglected in the discussion of so-called "unconventional" configurations.

The background of the technical recommendations is presented in Section 6 in the form of economical and ecological aspects of aviation, of flight areas envisaged and of new approaches and technologies. The essential technical recommendations follow in Section 7. General recommendations aiming at enhanced competitiveness will be found in Section 8. After final remarks in Section 9 the names of ASM members are given, who have contributed to the memorandum. The list of references closes the memorandum.

2 The Significance of the Aircraft Industry in Germany

The German aircraft industry with its product development and production capabilities is still regarded as strategic industry by the politics. This became apparent some time ago, when – after the media disclosed Daimler's intention to hand over its EADS shares – the Federal Government undertook activities to secure the German influence at EADS. The rationale is to be found in high ranked positions in management, and lucrative production work, which one would not like to drop. Less in focus are the innovation performances of the field of aeronautics and the resulting technology transfer into other areas, which are of great importance [1]. (The recent unsuccessful plans for a merger of EADS and BAE will not be discussed here.)

However, the strategic importance of the aeronautical industry can also be deduced from the federal support to aviation research programmes, almost unnoticed by the general public. These programmes are aimed at strengthening the technology base and improving the economical and technical situation.

If the aircraft industry is of strategic importance for Germany, its military part has to be considered too. Its innovation requirements and achievements are especially high. In that area however the danger exists, that the former military aircraft manufacturing asset – now concentrated in the Air-Systems Division of Cassidian (an EADS company) – loses its innovation capability and is reduced to maintenance and product support functions. But this would be in contrast to the assertions from the politicians and should evoke a differentiated consideration.

In this context a study of the European Air and Space Academy has to be mentioned, in which the danger is seen that Europe before long will lose the capabilities to develop manned and/or unmanned combat aircraft, if there will not be a counteraction by the politics [2]. The same is true for hypersonic air vehicles with respect to military reconnaissance systems, and also for advanced space transport systems.

Military air vehicles and hypersonic vehicles with their extremely high technological challenges and the corresponding innovation potentials should be seen in the context of potential future strategic requirements and not be dismissed by the argument of lacking early added value.

3 The German Aircraft Field of Aeronautics and the International Competition

The German field of aeronautics is no more autonomously "German". It is very closely connected with that of other nations. This also is true for the aviation research outside the universities, to a lesser extent for university education and research. In other words, if the long-term development of the field has to be looked at, these connections are to be considered. It is therefore necessary to consider five big challenges:

- The economical and ecological constraints, combined with an expected continuing growth of air traffic (passenger and cargo transport), require economically efficient, safe and environmentally compatible air vehicles. This is laid down in the corresponding documents of the Advisory Council for Aeronautical Research in Europe (ACARE) ("A Vision for 2020", "Beyond Vision 2020 (Towards 2050)") and shall not be repeated here.
- The current competition situation with the US-American aircraft industry.
- The current, and especially the future competition situation with the aircraft industries of the BRICC countries (Brazil, Russia, India, China, Canada).
- The opening of new markets in countries with weak traffic infrastructure.
- The positioning of the German aircraft industry together with research and education within the European context. In the end this again is the question of the strategic value of the field. One can observe the tendency to hand over the product definition and development to one or more European partners, which the ASM consider to be wrong. The aeronautic companies are no longer – with respect to the timeframe of 1920-1980 – more or less "innovation companies" [3], but ordinary, i.e., privately owned industries, which are profit-oriented. As soon as the common opinion is, that product development costs only money and solely production is interesting, the demise has already set in. In our case it means that it is against the strategic German interest to hand over the product definition and development capabilities to the European partners and restrict oneself only to the production.

4 The Aircraft vs. the Surface Transport Vehicles

The aircraft treated here has two – not always separate – tasks: (1) transport of passengers, (2) transport of cargo (most often, but not necessarily, in combination with (1)). Added to that comes the acquisition of information, a task, which may take a bigger significance in the future. The air traffic is competing with the road traffic (tasks 1 and 2), with the railway traffic (tasks 1 and 2), and with the waterways (task 2).

The transport by air in general is dedicated to the transport over longer distances, and is not at all relevant for local area traffic, e.g., that in the periphery of cities and urban agglomerates. This is true for both passenger and cargo transport. In the following considerations it is necessary to differentiate. In general a bad rating is given to the air traffic with respect to ecology in comparison to road and railway traffic. The bad rating for the air traffic is – mostly – politically/ideologically biased, although the economic interests of influential circles cannot be excluded.

The faulty point of view generally results from the fact that only the direct fuel consumption – and therefore the emission of pollutants – is considered. That is the amount of fuel, which is required to transport one passenger or a piece of cargo from location A to location B. This goes that far, that in the case of passenger transport by an aircraft the added cargo load, which counts for a substantial part of the business, is not taken into account at all.

Much more important, and this is a fundamental point of our argumentation, is that – by limiting the analysis to the point-to-point fuel consumption parameter – the comparison at the global system level is neglected. The following observations can – and must – be made:

1. The air traffic has a very low surface consumption compared with the rail traffic and the road traffic. The Federal Republic of Germany has a surface of approximate 357.100 km^2, of which 4.8 per cent - i.e., approximately 17.100 km^2 – are dedicated to traffic expanses [4]. From this surface the road traffic requires approximately 91.6 per cent, the rail traffic approximately 7 per cent and the air traffic 0.6 per cent [5]. This means that the road traffic requires 15.700 km^2, the rail traffic 1.200 km^2 and the air traffic 102 km^2. The number of transported passengers per surface-unit could not be determined. However, a survey for the former West Germany showed for the air traffic a passenger-kilometre to surface unit ratio more than five times larger than the equivalent figure for the rail traffic, and more than six times as for the road traffic (sources BMV/Lufthansa 1989). The air traffic therefore is by far the traffic type with the lowest surface consumption per passenger-kilometre.
2. The specific primary energy needs of the air traffic are low in comparison with the road and rail traffic. Usually, the fuel consumption of cars is given in litre per 100 km. Nothing is said about the transportation performance. In aviation, and also at the German Railways Company, the consumption performance is calculated in terms of litre fuel per person (P) and kilometre: litre/(Pkm). However, in order to compare correctly the energy needs of different transportation means, it is necessary to use a common, dimensionless comparison reference. In [6] the specific primary energy need – e_P – is introduced as a basis. For a car the primary energy need can be expressed as: $EP = e_P \times 3{,}21$ litre/kilometre.

   The lower the e_P of a means of transportation is, the more economic the transportation with this means is. For aircraft of the Airbus type it emerges a value of e_P = from 0.94 to 0.83 for a 150 seater (short distance) and respectively a 300 seater (long-route). For the high-speed train of ICE type values of e_P = 1.24 to 2.35 emerge for speeds of 250 km per hour up to 350 km per hour. For an upper class car, one gets e_P = 1.73 and for a big container ship e_P drops to 0.0035.

   These numbers reflect and compare only the direct fuel consumption and hence the direct costs of a transportation means. They do not include the respective traffic bearer's infrastructure costs. The costs of operating, maintaining and sustaining the traffic systems must be taken into account when comparing them. Detailed data in this respect is not available. If data is given for the infrastructure, it is not clear what actually is behind it, see the next paragraph. A very crude approximation would be to look at the surface consumptions. Then the air traffic would come out with the lowest infrastructure costs.

3. The cost structure of the air traffic appears to be favourable. The classification of the cost structures of the traffic bearer in [7] distinguishes costs of the business, the infrastructure, the accidents and the environment. For the year 2008, for example, in Table 1 the stated cost structures result. The economic costs are declared. For the rail traffic one finds the statement of an economic cost coverage rate of 52 per cent only, whereas the operative cost coverage rate amounts to 107 per cent [7]. For the traffic bearers rail and air, no accident costs are stated. The air traffic however is the safest traffic type worldwide [8]. For the year 2011, IATA states that in the worldwide air traffic about 486 people lost their lives. The number of passengers worldwide was approximately 2.6 billions.

Table 1: Cost structures (economic costs) of the passenger services of traffic bearers in Germany in the year 2008 in billions Euro. ÖPNV: public person local traffic. Data source [7].

Type of Traffic	Operations	Infrastructure	Accidents	Environment	Cost Coverage [%]	Subventions
Road	164	24.2	31.8	13.6	80 – 84	3.32
Railway	6.1	7.1	-	0.9	52	9.88 (with ÖPNV)
Air	19.9	6.1	-	1.4	95	0.517

In the statements about the cost coverage for road and air traffic it is assumed that the operating costs are covered completely. It is not recognizable to what extent the infrastructure costs of in particular the rail traffic include the operation, maintenance and sustainment costs of the whole system. The accident costs are the accident consequence costs. The environment costs are costs in the context with air pollution, noise, climate (CO_2) and so on. Also here it is not recognizable, to what extent the environment costs of the properties are included.

The transportation performances of the individual traffic bearers in the year 2008 are evaluated in [7] in terms of passenger-kilometres (Pkm): Street 869,6 billions Pkm; Rail, long distance and regional traffic (FuRV) 82,5 billions Pkm; Rail, ÖPNV: 55.6 billions Pkm; Air 189.1 billions Pkm.

4. The air traffic has the lowest specific subsidies in the comparison. The specific subsidies of the traffic bearers – in ascending order – are air: 2.7 EURO /(1000 Pkm); Street: 3.8 EURO/(1000 Pkm); ÖPNV: 50.1 EURO/(1000 Pkm); Rail FuRV: 86.0 EURO/(1000 Pkm). For details see [7].
5. The specific environmental costs of the air traffic are low. The specific environmental costs of the traffic bearers result to – also in ascending order – Rail, (FuRV + ÖNPV): 0.0065 EURO/(1000 Pkm); Air: 0.0074 EURO/(1000 Pkm); Street: 0.0156 EURO/(1000 Pkm). For details also see [7]. Whether the environmental costs of the respective infrastructure are included, is not apparent.
6. The population's noise burden of the individual traffic bearers can hardly be quantified in a comparative way, even if the issue is well understood [9]. However, one can assume that the noise burden of the road traffic and the rail traffic in sum is several times higher than that of the air traffic. This is confirmed by the results of a noise mapping done by the German environment federal office (UBA) in accordance with the environmental noise guideline of the EC [10].

In the context of the noise burden a conditioning of wide population circles is to be observed: the sound of a high flying aircraft is felt much more disturbing than the noise of the street or rail traffic in the immediate surroundings. However, it is not allowed to underestimate that. In particular the noise of starting aircraft in airport proximity is a big problem. It hence represents a very big challenge for the aircraft industry, for the airport business and for the air traffic management.

In summary the transport system aircraft has a good balance compared to each of the other transportation systems. It is therefore misleading to speak evil of the air traffic because of an insinuated negative climate-balance. One only needs to look at the specific primary-energy-consumption comparison given above to put things right. As a matter of fact, the true climate balance must include the infrastructure costs. Even if one assumes as given the infrastructures of the traffic bearers, road and rail, i.e., the respective transportation networks, at least the impact on the climate balance of maintaining the existing infrastructure must be considered. The air traffic therefore has – on the basis of its low surface consumption as shown above – a big advantage. A quantification of this issue is urgently necessary.

On the other hand, the construction of new rail and road infrastructure gets an ever increasing acceptance problem from the public community. Even the – for itself reasonable – proposition, to transfer traffic from the road to the rail, increasingly meets resistance in the population. That moreover is stirred up and used by political fractions of all shades according to the situation. Prominent examples in recent time are the resistances against the reconstruction of the Stuttgart main railway station (Stuttgart 21) and the extension of the North-South-Magistrale (Baden 21) in Offenburg. The necessary extension of the incoming lorry traffic infrastructure to the Brenner tunnel through the Inntal is expected to be met with considerable resistance in the area between Rosenheim and Kufstein, which has already commenced.

In an area, state or continent with a structure of grown transportation systems, the aircraft obviously has no very big new potentials, as distinguished from countries with weaker traffic infrastructure. Here even individual traffic with small aircraft is conceivable. Corresponding studies are the European Personal Air Transportation System (EPATS) study [11, 12], but also the NASA studies about the Personal Air Transport (PAT) with, among other things, the vertically starting and landing electro aircraft Puffin [13]. The low German participation with the EPATS study group is indicative (2 per cent of Germany against 34 per cent of Poland and 25 per cent of France and the Netherlands each).

However, for countries with a weak traffic infrastructure the goods transportation by ad-hoc cargo aircraft is a very interesting option, look at the ECOLIFTER-Concept [14], and potentially is an attractive business-field (see below Sub-Section 7.4). This is applicable even to areas with a structure of grown transportation systems. With a relatively small fleet of aircraft, for example, a considerable part of the goods transportation could be handled over the Alps. Here no restrictions on thinking should exist. The Brenner Tunnel with its input routes, citizens' protest from all sides, and the long time of construction could be forgotten. The same is true for the feeder road traffic in congested urban areas where VTOL aircraft – not helicopters – could be operated with little surface consumption, great flexibility and acceptable noise emission.

4 To Remember: Some Basic Relationships

Richard von Mises in 1926 wrote that the aircraft now has gained its "world form", since "*... the development is completed in the characteristics, and the aircraft in its general design and in the majority of its construction parts gradually assumes final forms*" [15]. One can now speak of the "second world form" of the transportation aircraft with justification [16], or, in other words, of the "normal form." This features a transonic aircraft with a backwards swept, thick wing, a low wing arrangement (the high wing arrangement can still be found in military transportation aircraft and bombers), jet engines with axial compressor in nacelles located forward and under the wing, cylindrical fuselage and a tail assembly laying far behind.

Since a long time, there have been attempts to give impulses for the development of advanced aircraft with new, so-called "unconventional" airframe configurations. Before starting to elaborate this, two basic considerations are made. They concern on the one hand Cayley's design paradigm and on the other hand Breguet's range formula.

Cayley's Design Paradigm Cayley's design paradigm strives (first aspect) for a preferably unambiguous assignment of functions and subsystems, for example lift $\rightarrow$ wing, propulsion $\rightarrow$ engine, longitudinal and directional stability $\rightarrow$ horizontal and vertical stabilizer, payload $\rightarrow$ fuselage [17]. If the subsystems then are linked weakly and linearly, each can be optimized for itself largely independent from the others, and one optimizes the entire system with them simultaneously. This paradigm is a desirable basis for the approach in aircraft development, but also for the development of any complex technical product. However, since years this paradigm has become weakened more and more. Couplings of functions in the modern aircraft technology and subsystems become ever stronger. This leads to new design, development, and also business problems, but may also express the necessity of a post-Cayley design paradigm, Sub-Section 8.4.

The second aspect of the paradigm is the differentiation of the involved scientific-technical disciplines engaged in the definition and development of aircraft. This differentiation shapes the organizational/institutional structures of aeronautics research, education and industry. On the one hand it has led to the sequential and iterative procedure in the design processes as usual today. On the other hand it is one of the reasons for the enormous dynamics of the technological development of aircraft manufacturing. If however, the first aspect of Cayley's paradigm is weakened, the differentiation of the disciplines stands in the way of a more integral procedure. This aspect becomes more attention later in Sub-Section 8.6.

Breguet's Range Formula The range formula in its simplest form relates the flight range R with the parameters flying speed v, aerodynamic quality (lift/drag) c_L/c_D, specific impulse I_{sp}, as well as the structure parameters mass empty m_e, payload mass m_P and fuel mass m_F:

$$R = v \cdot \frac{c_L}{c_D} \cdot I_{sp} \cdot \ln\left(1 + \frac{m_F}{m_e + m_P}\right).$$

This range formula shows that the individual parameters for a constant range R can become "traded". In the case of a transonic aircraft, the highest attainable speed naturally is restricted by the drag divergence after exceeding the critical Mach number [1]. This is true for swept as well as for unswept wings. The critical Mach number depends on the thickness of the wing and its sweep angle. The thicker the wing or the smaller the wing's sweep, the lower is the critical Mach number.

If therefore an unconventional configuration, for example the so-called box wing configuration, has an aerodynamic quality c_L/c_D considerably lower than that of a conventional configuration, this must either be compensated by a higher flying speed v, an accordingly improved propulsion effectiveness I_{sp}, or a reduced mass empty m_e. If however this compensation is not given, the configuration is in deficit with respect to the range formula. Of course, other reasons might modify this observation, perhaps if particular value is put on the flight qualities, or if an unconventional configuration leads to an especially low noise emission.

The range formula can be also used to demonstrate the advances, which have been achieved in aircraft design since the 1970s [1]. Due to improvements of the aerodynamic design the aerodynamic quality of an aircraft of the Airbus type, represented by $(M \cdot c_L/c_D)_{opt}$, has been increased by more than 30 per cent (M is the flight Mach number). The developments of the bypass engines have led to a reduction of the fuel consumption by about a factor of two. In the last decade the big advances have been shifted to airframe structures made of carbon fiber materials. Reductions of the mass empty by 25 to 30 per cent can be achieved with them. Simultaneously, an improvement of the passenger comfort is possible by higher pressure and humidity in the cabin.

Generally, it can be supposed today that the second world form of the transportation aircraft represents the optimum form, in future however in combination with a stronger integration of lift and propulsion. Arguments for this supposition are, in each case in comparison to other possible configurations like tandem-, monowing-, multiple wing-, box-, or joined wing configurations:

- Clear configuration through a proper separation of the individual functions, in accordance to Cayley's design paradigm. This holds even if couplings (interferences) become ever stronger, for example due to the integration of big fan engines with the wing.
- Due to the separation of the lift function (wing) and the payload function (fuselage) relatively easy pressure control in the passenger cabin.
- Best utilization of the wing for lift production and for fuel placement as well as probably best achievable flight qualities.
- Simple aerodynamics compared to multi-surface aircraft, because of relatively weak interferences; however this is no more valid for aerodynamically unstable configurations, which will lead to a further drag reduction.
- No impairment of flight mechanical stability and flight quality from other lifting surfaces, especially in asymmetric flight conditions.
- Small pitching moment increments at lift variations through smallest distance of center of gravity and neutral point of the total aircraft compared to other configurations, except for all-wing configurations.
- Maximum attainable lever of horizontal and vertical stabilizer of all configurations and therefore a priori large stabilization and control surface volumes with accordingly small forces and small adverse drag. With reduced longitudinal stability small design corrections are given because of the relative insensibility against changes of the tail size.
- Easy controllability of the ground effect at take-off and landing;
- Probably simplest undercarriage design compared to other configurations.
- Good passenger handling and good airport compatibility (passenger access, emergency evacuation, optimum access to aircraft components for the purpose of visual inspection, maintenance, ...).
- Best accessibility to the engines.

To be considered as particular problem areas of "unconventional" configurations are the topics:

- Pressure and weight problems of non-cylindrical fuselage shapes.
- Adverse effect of the wing planform on the root bending moment and on the induced drag.
- Potentially problematic implementation of high lift devices.

- Possible restriction of the angle of attack at take-off and landing.
- Problematic ground movement, start and landing with big wheel distances of the undercarriage.
- Problematic gust alleviation with big wing depths, small wing loadings, and box wing configurations.
- Passenger acceptance of external view exclusively in ‘virtual mode’.
- Passenger-handling on the ground and in emergencies.

In spite of these considerations, it should not be excluded that new configurations are possible. However, it must be distinguished between short distance, medium range, and long-range aircraft. In any case it should actively be looked for new configurations. However, our considerations yield that, when an "unconventional" configuration is proposed, it must at least be cross-checked against the deductions from Cayley’s design paradigm and Breguet’s range formula, and also the arguments and problems listed above. This is valid, with possible exemptions, even for aircraft types other than the transonic aircraft, which is the primary object of attention here.

6 Background of the Technical Recommendations

The technical recommendations that are given in Section 7 refer to the economic and ecologic aspects of aviation (Sub-Section 6.1), while possible future flight regimes (Sub-Section 6.2) and new approaches, technologies and flight equipment, (Sub-Section 6.3), are to be envisaged.

6.1 Economic and Ecologic Aspects in Aviation

The consideration of economical and ecological aspects in aeronautics faces to some extent old, however also more stringent and partially quite new requirements. The aspect of sustainability, i.e., the conservation and preservation of resources, becomes increasingly important. The following points will get an ever-stronger prominence in the future (see also [18] to [20]), while the security of supply with a simultaneous climate compatibility plays a crucial role:

- Reduction of the consumption of
  - fossil energy sources,
  - materials (Al, Ti, Li, C, ...).
- Reduction of
  - exhaust gas emissions (CO_2, NO_x, H_2O),
  - noise emissions (take-off, flight path, landing),
  - operational surfaces (airfields, infrastructure).

6.2 The Envisaged Flight Domains

The technical recommendations given in Section 7 are not restricted to the civil transonic aircraft. Four "flight domains" and a range of new approaches and technologies are in the background. These partially have already been in discussion respectively in work since a long time, however until now did not find general application. A direct assignment to the following flight domains is only partially performed.

The flight domains are:

- Flight at subcritical Mach numbers, i.e., at speeds, in which the aerodynamic compressibility effects do not play a role. Essential characteristics of the subsonic aircraft would be a low wing sweep such that natural (passive) laminar flow over the wing is sustained partially or in total [21]. Such configurations henceforth can be worth to be considered if the ecological constraints become so big that a high flight speed and

hence haul capacity must be given up in favour of drastically lowered fuel consumption. This however implies no compensation via larger aircraft fleets and/or higher flight frequencies.
- Flight at such supercritical Mach numbers that makes wing sweep necessary, and which corresponds to the transonic aircraft of today (status quo). Here future stronger ecological and economical constraints can be met with a whole set of innovations. A very interesting approach in this sense is pursued in the study "Climate Compatible Air Transportation System (CATS)" of the DLR. The interdisciplinary consideration of a situational adaptation of flying speed and altitude yields ecological advantages, and also economic effects for the flight equipment operator and the passengers.
- Supersonic and hypersonic flight, that admittedly is questionable for ecological reasons, but can be interesting for specific space transport and/or military missions.
- Flight with short and vertical take-off and landing. Flight vehicles of this kind are the classic helicopter but also the short and vertical take-off and landing vehicles, as it has been proposed in Germany in the 1960s for a possible VTOL air traffic [22].

6.3 New Approaches, Technologies and Flight Equipment

New approaches, technologies and flight equipment are in the background, for example:

- Active utilization of the structural flexibility of the aircraft with extremely lightweight and flexible structures, which essentially concerns the wing. While including the two aspects, this utilization goes beyond the classic "aeroelastic tailoring" and the aeroservoelasticity [23].
- Unstable aircraft layout with artificial longitudinal stability for the sake of drag reduction.
- Passive and active boundary layer control for drag reduction.
- Alternative fuels: hydrogen, methane, methanol, and fuel combinations.
- Big airframe volumes to accommodate alternative fuels.
- New propulsion concepts: multi-cycle engines, electric and hybrid-electric engines [24], and advanced Diesel engines.
- Coupling of drag and propulsion mechanisms. This topic has been discussed already in the 1960s in [25] (Chapter K II: The interaction of drag and propulsion mechanisms) and in [26].
- Flight vehicles for short-/ultra short vertical take-off and landing.
- "Powered glider" configurations.
- Unmanned systems (probably for cargo transportation only).
- Big aircraft, also as seaplanes or ground effect vehicles (for sea aircraft an EU study is being carried out – in view of the ACARE Vision 2020 – "Future Sea Aircraft Traffic, FUSETRA" [27]).
- Dirigibles.
- "Unconventional" configurations: forward swept wing (which possesses a very interesting potential of natural laminar flow [28]), blended wing/body, variable geometries.

Not taken into account in the technical recommendations have been possible developments that still look rather futuristic today, but which could profit from advances in quantum computers, virtual flight, nano technologies, low-energy nuclear reactions etc., see for example [29].

7 Technical Recommendations

The technical recommendations reflect individual views of the ASM members. In the end, however, they are the result of collective discussions. The single topics refer to the overall system aircraft, as well as to the definition and development processes and the involved scientific and technical disciplines. However, no claim of completeness can be made. Some of the recommendations may have already been put into practice, respectively are in the realization or preparation phase. Research and development topics, that have been proposed before, but did not find their way into the industrial application, are presented here, too. Unfortunately, due to the lack of specific expertise within the ASM, no recommendations can be given for some important technical topics, like – for example – propulsion.

The recommendations deal quite shortly with the object and its innovation demand, and sketch proposals for accordant solutions.

7.1 Innovation Demands with respect to the Possible Development of Civil Aviation

The Object With respect to shape, propulsion, flyability and controllability, avionics, etc., as well as regarding the industrial processes of design and development, the present airliners are the result of a development, which began after 1945. It is possible that this development gradually leads into saturation. However, economical and ecological constraints may lead to new, conceivably also radically different solutions, see Section 6. However, the fundamental connections and problem areas sketched in Section 5 are still effective in the background.

The new economic and ecologic considerations not only involve the aircraft as such, but also the infrastructure of civil aviation, namely airports including their connection to other traffic systems and the general airspace utilization, see for example [30]. In this regard, the requests and problems are especially demanding in countries with highly condensed settlement structures and a well-developed effective traffic infrastructure. A contributing factor is a population, which on the one hand accepts the air traffic in all beneficial aspects (human mobility in terms of touristic and business trips, transportation of goods and food), while on the other hand vehemently fights against any consequence of the air traffic, like the demand of additional infrastructure.

However, the further development of civil aviation does not only depend on the economical and ecological constraints, but also on the development of the world economy, the global energy situation and the political realities.

It is hard to foresee, which influence these factors will have on the further development of the civil aircraft. The today's mature configuration of the civil aircraft, emerged at the end of the Second World War, has reached a high level in terms of transportation performance, economic viability and operation. Improvements are possible in principle, but also deemed necessary, in particular with regard to the ecological aspects of the aircraft.

Innovation Demand Innovations would be – for example – the introduction of artificial longitudinal stability for the minimization or total cancellation of the trim drag, the reduction of the friction drag by boundary layer control, the utilization of new material and structure concepts, new production methods in the area of the fiber composite technology, new propulsion concepts and flight control concepts, unconventional configurations and finally radically new product definition and development processes and process technologies. To prove some of these innovations demonstrators are to be provided. Innovative also would be concepts like very big transportation aircraft, even very big sea aircraft and V/STOL aircraft for the feeder traffic. These concepts are to be seen in the context of the individual traffic situation of states or regions, see Section 4.

Solution Consideration Solution considerations are not discussed here. To some extent they can be found in the following recommendations.

7.2 German System Competence in Aircraft Design and Development

The Object Remarks have been made in Sections 2 and 3 about the status of the aeronautical industry in Germany and the situation of the German field of aeronautics with respect to the international competition. The manufacturing of large aircraft stood in the foreground there, whereas the manufacturing of light aircraft – indeed a very successful segment in Germany – was disregarded. This is applicable also to the following considerations.

If the (aircraft) development capabilities within Cassidian Air-Systems will be given up, it must be concluded that Germany does not possess any more the system capability in large aircraft construction. System capability means the definition and development capability. Of course one can argue that the system capability is not absolutely necessary. However, it should not be in Germany's interest, to give up completely product definition and development in favour of European cooperation. Admittedly innovations are possible in such cooperation. However, the incentives are much larger with the whole system in the background. In this context the attention must once again be drawn to the military aircraft business, where innovation has an even higher and more encompassing importance.

With respect to the largely given up system capability, one can hear in Germany voices asking, why then still aeronautical research and education? One better can spend the money on other things. Considering the emotions against aeronautics of wide circles of the German society and politicians, such remarks are dangerous.

Notwithstanding, the ASM members are still of the opinion that everything should be done to reconstitute the large aircraft system capability, as this will generate technological and industrial challenges for the German economy that must not be underestimated.

System design capabilities should also exist with respect to supersonic and hypersonic aircraft. This is applicable not only to the design of military aircraft, see Section 2, but also to future space transportation systems. In the German Hypersonics Technology Programme – carried out in the 1980s and until the mid 1990s – the two-stage-to-orbit, fully reusable space transportation system SÄNGER II has been investigated [31]. The rationale was a long-term geostrategic approach, namely to get the capability to go into space directly from Europe, thus avoiding the politically risks to depend upon other continents for the access to space. Today such long-term strategic approaches seem to have been completely given up in Germany and Europe. However, the ASM members doubt that we can afford to maintain this attitude in the long term.

Solution Consideration In view of the comfortably large order backlog of Airbus it has to be assumed that the development capacities in Toulouse will be completely tied up with that business for a long time. This could be a good opportunity for Germany to take over the definition and the development of, for instance, a A320 successor in Bremen or in Hamburg. If this would become reality, recommendations given in the following sections could be implemented, that focus on the future economical and ecological challenges. In particular, the introduction of the proposed new definition and development methodology would be a great and inspiring challenge, see Sub-Section 7.6, with aspects of the Virtual Product, Sub-Section 7.7.

The definition and development activities, that should take place with the proposed new definition and development methodology, would need to be supported by research activities carried out within the DLR, at the universities, at the Bauhaus Luftfahrt, of course in cooperation with Innovation Works – the EADS research laboratories. The national aeronautical research programs should be given a new focus, too.

The ASM members however emphasise that the proposed German development organization should give up, at least to a degree, the old paradigms, procedures and structures, as elaborated in more detail in Section 8 "General Recommendations to Improve Competitiveness". The old paths, admittedly well proven, but questionable with respect to the future challenges, have to be left in favour of such ones that are more fit for the future. Of course this is accompanied with risks, but in the long term, such change is necessary anyway.

For Airbus this would have four positive effects. At first, Germany economically would be viewed positively, secondly, an internal competition would be installed, that, placed well, could promote innovation very much, and, to the third, could create an element of long-term safeguarding of the future.

The fourth positive effect consists in creating an incentive for the very keen German junior engineers to join the aircraft industry and remain there. One can frequently observe today that the migration of the definition and development activities away from Germany is not at all an incentive for these people.

In view of supersonic and hypersonic flight technologies ways should be found to maintain the design capabilities of Cassidian Air-Systems. In addition technological breeding nuclei for hypersonic flight vehicles should be established at industry and research. These nuclei are to be embedded in a European network. However, not only predesign studies must be made, but the technological key problems must be attacked [32].

7.3 General Design Requirements

The Object In parallel to the nowadays mainly dominant economic viability aspects (direct operational costs, life cycle costs) today's aircraft design must consider more and more sustainability demands. The sustainability aspects influence many facets of the design with different manner and strength, for that no mature systematic exists until now. These influences need to be analysed and quantified as well as mapped into a corresponding design system.

Innovation Demand The economical and ecological aspects must be considered in a linked manner in the design process. Suitable technical measures, like for example boundary layer control, artificial stability of the longitudinal movement, new materials and manufacturing techniques, unconventional propulsion and propulsion integration concepts are to be assessed. Corresponding evaluation criteria are to be defined and weighted up mutually. Their "tracks" must be always traceable across the technical disciplines and throughout the overall design.

Solution Consideration With respect to the ecology of the entire design "efficiency measures" have to be developed. These measures must be provided in mathematical form. Specific target figures and functions that lead to the optimum total design have to be defined, whereby rational optimization processes will play a big role. Generally, more knowledge has to be generated already in the early phases of the design, which means that it is necessary to produce deeper product knowledge at an earlier time than nowadays ("front loading"), Sub-Section 7.6. Likely, the most effective measure to reach this is the introduction of the "Virtual Product" concept, which will become an essential element of the long time discussed, but generally still not realized "concurrent engineering", Sub-Section 7.7.

7.4 Design Requirements for Large Aircraft

The Object This recommendation deals with very large transportation aircraft with freight capacity of approximately 250 tons for the high-frequency service of large shipment volumes. These planes are not derivatives of passenger versions. In order to exploit the opportunity to develop special effective load/unload concepts, the use of standard containers is preferred. In the case that military airfields can be used, the requirement of the 80 m x 80 m box imposed by civil airport infrastructures can be dropped. The cruise speed shall correspond to the usual range standard from Mach 0.8 to 0.85, such that the air traffic control can allocate optimal slots.

Innovation Demand For a short transit time a new load/unload concept is necessary that allows to use the take-off/landing capacities of the airfields to a high extent. For this purpose it may be necessary to find specific and innovative solutions for the shaping and pressure ventilation of the fuselage. For avoiding limitations to night flight operations special attention must be given to engine-airframe configurations suitable to reduce the noise footprint on the ground.

Solution Consideration A fuselage that is broader than round – a so-called hot-bottle shaping – is optimally suited for the simultaneous loading and unloading at all load positions. This implies broadside openings at both fuselage sides, through which a standard container of 6 m length can be pushed into and pulled out. This requires fuselage widths of about 15 m. According to the kind of freight the containers are simply driven into the fuselage or, if pressure ventilation/air conditioning is necessary, are put into special pressurised tubes, that are used from case to case. The containers are directly pushed from trucks on the same level into the fuselage compartment. Therefore no additional equipment for loading is necessary. For noise reduction, the engines should be installed between the twin vertical stabilizers above the aircraft afterbody. Particular deflection fences in front of the fan inlet and behind the nozzle divert the noise mainly upward.

7.5 Design Requirements for VTOL Aircraft

The Object This recommendation deals with fixed wing aircraft with VTOL-capability, not with the most-widespread one, the helicopter. The spectrum considered here extends from the 2-seater for police tasks to the feeder liner with ranges of about 1,000 km. This class of air vehicle can be operated from smallest surfaces without runway (RIA: Runway Independent Aircraft), preferably in the area of cities of a size of about 50,000 inhabitants, and as feeder or business plane.

Innovation Demand There is generally a lack of VTOL-passenger aircraft operating at cruising speeds compatible with the standard slot system of the air traffic. For security and passenger acceptance considerations open rotors or propellers as well as tilting elements should be avoided. Noise abatement issues deserve highest priority. For commercial applications long hover times need not to be provided. Take-off and transition to cruise must be limited to 15 seconds, and landing transition plus landing to 90 seconds at maximum.

Solution Consideration For smaller aircraft modern turbocharged piston engines offer advantages with respect to noise, fuel consumption, fast control reaction and low cost compared to gas turbines. The development of specific lifting engines does not make sense as it would cause only additional expenditure and costs.

For bigger units, the application of several gas turbines located close to the centre of gravity delivers the required redundancy. The lifting takes place by impellers that are driven over long distance shafts or even electrically. The cold airflow avoids the problem of sucking hot exhaust gases into the turbine intakes due to the unavoidable recirculation. In the transition and hover phase ‘ad-hoc’ all around-view-sensors protect against collisions with objects in the surroundings.

Dedicated take-off and landing fields (VTOL-centres) resembling the design of monopteros temples of about 200 m diameter and 100 m height provide a complete infrastructure for the VTOL-operations for aircraft up to 100 seats. In about 30 floors all services can be accommodated:

- a take-off/landing surface at the very top,
- below it roofed docking places for the aircraft, with aircraft carrier–like elevators for lifting the aircraft up and down. Further down the dispatch areas and the luggage compartment,
- clinics, restaurants, hotels and finally shopping plazas and car park decks on the lower floors.

All these lower floors are accommodated in the periphery between the columns of the monopteros. The floors of the parking area are in the inside. These VTOL-Centres can be fully integrated into the big airports without large area demand. The access of the passengers takes place through subways from outside the airport-restricted area, both by road and railway lines.

7.6 Definition and Development Methodology

The Object The today in many variations existing procedure in the product definition is marked by a relative incomplete description of the physical and functional properties of the flight vehicle in the early definition phases (concept phase, preliminary design), which leads to a limited product knowledge. This unsatisfactory situation is accepted, although there is a broad consensus that a large portion of the operational and life cycle costs is fixed in the early definition phase. Important determinations of static and dynamic qualities of the airframe are obtained very late in the development process – only after the airframe becomes assembled for the first time. Depending on the size of the new technology insertion in extreme cases only extensive flight tests (system identification) provide the necessary depth and accuracy of the database of the vehicle – the product knowledge.

An insufficient knowledge during the product definition leads to risks. These usually lead to additional costs in the product development, especially when the necessity of so-called repair solutions emerges only in the late development phases – or during the flight-testing. Provisions for losses usually cover these additional costs, whereas non-fulfilment of the guaranteed performance leads to a financial compensation of the customer. However, these additional costs can become so high that a project must be given up in late phases, even during the flight-testing, and/or that the manufacturing firm itself gets into dire financial straits. Drastic examples of both cases are known from the past.

What has to be seen critically in view of this scenario is that after the project end normally no systematic reviews of the definition and development-processes are performed, see Sub-Section 8.2. These should be mandatory when big problems occurred, but are desirable in any case.

In future the classical interconnections mission $\rightarrow$ configuration $\leftrightarrow$ design must get the additional objective function ‘ecology’. Principally economics and ecology of the product can be reconciled. Basic prerequisite is the definition of ecological standards or efficiencies, Sub-Section 7.3. A change however from the presently used approach for the product definition seems absolutely necessary for reducing – or even avoiding completely – the problems and risks previously discussed.

Innovation Demand When strong economical and ecological constraints require large technology leaps – see Sub-Section 7.1 about innovation demand – any undesirable effect caused by design inconsistencies must be identified and quantified early. With reference to ecological aspects the necessary statistical database for the early definition phases today is still missing. Therefore innovative procedures must be developed for the preliminary design.

Solution Consideration Three main focal points for solutions are seen:

Main focal point A): Introduction of new procedures based on information technologies for the product definition already in the pre-design phase to achieve the necessary deeper knowledge at an earlier time, the desired "front loading":

- Use of graph-based design methods (GBDM) in the definition phases. GBDM's are computer-aided processes with automatic documentation of the design steps and solutions, including the discarding of potential solutions, as described in [33, 34].
- Implementation of phase-adequate (concept-, pre-design-, design- etc. phases) numerical simulation and optimization procedures (Virtual Product, Sub-Section 7.7), to achieve a more exact mathematical description of the physical and functional characteristics of the product at an early stage. The emerging database of the product, which iteratively becomes more accurate and more reliable, leads to an improvement of the results of all necessary system simulations and performance identifications, allowing more realistic demonstrations for the customer(s) and enabling early briefing of pilots and maintenance personnel.

Main focal point B): Very early consideration of configuration alternatives like wing-body-blending and other alternatives.

Main focal point C): Consideration of mission alternatives, for example aerial refuelling, stopovers and so on.

7.7 Virtual Product, Multidisciplinary Simulation and Optimization

The Object Albeit in forms that may differ from company to company, basically three problem areas preclude the achievement of the degree of product knowledge deemed necessary in the early product definition phase, Section 7.6:

• The product definition in aircraft industry in principle still follows the first aspect of Cayley's design paradigm, Section 5. The differentiation of the technical disciplines (second aspect) is exacerbated by the cost centre and line organisation structures of the companies, see Sub-Sections 8.6 and 8.7.

• In the crucial early stages of a project, the time and cost pressure is usually so high that basic settings are often made free-hand and later are not even questioned. A documentation of the rationale for those decisions does not take place, often also because it is considered by some persons to be knowledge for the sake of domination.

• The task of project management to achieve overall optimization of the product with the various technical disciplines is complicated by the rule of no cross-disciplinary structures with only limited interaction opportunities.

This object relates to the introduction of phase-adequate numerical simulation and optimization processes – Virtual Product (VP) –, see also Sub-Section 7.6, which in the broadest sense is likely to make it possible to overcome the first and third of the addressed problem areas.

Innovation Demand To reduce or even eliminate the three problem areas, the following measures appear to be appropriate:

• The development of a post-Cayley's design paradigm, see Sub-Section 8.4.

• The replacement of the discipline-oriented, iterative product definition and development by an holistic, weakly-iterative design methodology, see Sub-Section 8.6.

• The development of the VP as a high-fidelity mathematical/numerical representation of the physical and functional properties of the product, here the flight vehicle. Core of the VP are numerical multidisciplinary simulation and optimization methods (MDSO methods [35]) with adequate physical flow modelling (Sub-Section 7.8) and an accurate physical representation of the object (Sub-Sections 7.9 and 7.10).

Solution Consideration The solution consideration is restricted here to the Virtual Product as the most advanced IT-based process technology. The perspective problem, "Numerical simulation of the elastic free-flying and manoeuvring aircraft, including the propulsion system in steady state and transient operation conditions" has been formulated in the mid-1990s in a memorandum [36].

In the early definition phases the product knowledge is limited, but then it increases steadily, whereas the goal is to let it move quicker to a higher degree of detailing than the current approach permits [35]. This means that the definition and development phase-appropriate modelling must „grow“ from initially simple product models, such as the substitute models for the elastic structure, to high-fidelity product models at the end. The latter then must represent the entire flight control chain of the aircraft from the air data sensor to the actuators of the aerodynamic control surfaces, including non-linear aerodynamics, structural elasticity and the engine control system.

The following steps are required to achieve the VP in this sense (these steps apply only to the technical side of the issue, see Section 8 for the organizational issues in the aircraft industry):

• Depending on the project, identification of the baseline configuration, see Sub-Sections 6.2 and 6.3, the phase-adequate product models, the substitute models, i.e., simplified models, and the subsystem models.

• Definition of the key points of the flight envelope.

• Identification of the respective disciplinary interactions and the disciplinary numerical codes.

• Definition of coupling strategies for the necessary multidisciplinary processes.

• Creation of common interfaces for the transfer of the boundary conditions and for the data exchange.

• Identification of the requirements on the multidisciplinary optimisation strategies and algorithms.

• Development and advancement of the MDSO processes.

These steps are to be defined and agreed upon by all involved disciplines and persons, including those from the research establishments and universities that already have produced high quality MDSO methods and results. From the beginning verification and certification procedures must be taken into account.

7.8 Aerodynamics

The Object The recommendations for the discipline aerodynamics relate to two problem areas: A) improvement of the aerodynamic efficiency of the aircraft, B) flow-physical modelling in terms of the demands of Sub-Section 7.7 (Virtual Product, multidisciplinary simulation and optimization).

• Problem area A): The background of the technical recommendations (economical and ecological aspects, flight domains, new approaches and technologies) as discussed in Section 6 leads to different demands – in particular with regard to aerodynamics. The most important ones are a stronger integration of the elements of the aerodynamic shape with the propulsion system, a reduction of the viscous drag by means of boundary layer control measures, and the introduction of a flight control system for artificial longitudinal stability.

• Problem area B): The numerical methods for multidisciplinary simulation and optimization as elements of the Virtual Product require significantly improved flow-physical models of high accuracy and reliability, which – depending on the flight conditions – might include the need for an improved thermodynamic modelling.

Innovation Demand The needs for innovation are presented as follows:

•Problem area A)

- Trade-off studies of the aerodynamic advantages of highly integrated wing-body (blended) configurations in comparison to classical configurations with different degrees of integration.
- Development and verification of optimal laminar shapes of fully integrated configurations (laminar aircraft).
- Improvement or development of new boundary-layer control devices for classical and highly integrated configurations.
- Further development of configurational approaches to achieve artificial longitudinal stability.

• Problem area B)

- Accurate and reliable non-empirical criteria and models for laminar-turbulent instability and transition as well as for re-laminarisation phenomena.
- Receptivity models, i.e., mathematical models that describe how disturbances enter the boundary layer: a) atmospheric disturbances (turbulence intensity, temperature and other fluctuations), and b) aircraft-specific disturbances (surface properties, vibration, noise). All in terms of laminar-turbulent instability and transition-phenomena and turbulent flows.
- Turbulence and transition models for separated and vortical flows.

Solution Consideration Solution thoughts are:

• Problem area A)

- Laminar aircraft: Arrangement of tank volumes and engine(s) around a conventional cylindrical passenger/freight aircraft fuselage for an optimum laminar fuselage configuration.
- Laminar flow: for swept wings appropriate design of the wing and the high-lift system to achieve the reduction of friction drag by natural (forward swept wing) or active (suction) laminarisation.
- Direct coupling of the drag and propulsion mechanisms for the improvement of the propulsion efficiency.
- Artificial longitudinal stability: development of redundancy approaches to allow a more or less conventional operation of the aircraft in flight and on the ground.
- Micro-Electro-Mechanical Systems (MEMS) for transition control and novel airframe surface-temperature management approaches to reduce turbulent friction drag.

• Problem area B)

- Further development of non-local and non-linear non-empirical transition models with adequate receptivity models.
- Further development of statistical turbulence models and hybrid approaches (RANS-LES coupling) with suitable receptivity models.
- Acquisition of experimental modelling and verification data in the DNW and ETW wind tunnels and in flight tests. Up to now databases have been obtained solely in wind tunnels with low Reynolds numbers or insufficient Mach number/Reynolds number similarity.
- General departure from the current method-centred approaches and switch-over to problem-oriented approaches through a rigorous combination of analytical, experimental (ground and flight testing), and numerical methods.

7.9 Materials Science and Engineering

The Object Materials and their properties: metals such as steel, titanium and aluminium and their alloys have the advantage, that static loads can be very well transferred. By plastification they become notch insensitive to static loads, but remain notch sensitive to dynamic loads. The main disadvantage is the high density of the metals, and the relatively low strength and rigidity as compared to the properties of fiber composites.

Fiber composites are important alternative materials. They consist of fibres that are embedded in a matrix (for example epoxy resin). The carbon fibres offered today, can be divided into three groups: high-strength, semi-rigid and high-modulus fibres. At a density of 1.6 to 2.0 g/cm^3, the fiber has a strength divided by the density of 150 to 220 km. Related to its density the elastic modulus of a high-modulus fiber is extremely high, about five times higher than that of steel. The fiber itself is orthotropic, the longitudinal stiffness is much higher than the transverse stiffness. The ultimate elongation is about 1 per cent. The thermal expansion coefficient is approximately zero or negative in the longitudinal direction of the fiber, whereas it has a positive value for the lateral direction.

The available glass fibres have a density of 2.55 g/cm^3. The fibres are isotropic, the modulus of elasticity is in the range of aluminium, but the fibres have a significantly higher strength. The elongation at failure is 4.5 per cent.

The fibres are usually bonded to epoxy resins. These are isotropic and have a nonlinear stress-strain behaviour. The resins have a modulus of elasticity from 3,000 to 6,000 N/mm^2, a tensile strength of 40 to 140 N/mm^2 with an ultimate elongation of 2 to 10 per cent. They can be used up to 170°C. Their density is about 1.2 g/cm^3. That reduces the density of the fiber-resin composite. The density of carbon-fiber epoxy is only half of that of aluminium.

The fibres are imbedded in the resin. The properties are usually given for unidirectional composites with a fiber volume fraction of 60 per cent. The strengths of the multidirectional composites correspond to those of the calculated values without plasticity taken into account. Notches have a significant impact on the static strength – unlike with metals – but a small one on the dynamic strength. The Wöhler curves have a relatively low strength decrease, the ratio between static and dynamic strength is small. Thus far longer inspection intervals result for fiber composite structures than for metal components.

Impact loads can cause damage to composite structures and, in particular, significantly reduce the compression strength (compression after impact). Using fracture mechanics parameters (energy release rate), the damage can be assessed and the behavior influenced. The effect of scarf joints and notches on the mechanical strength can be calculated with these values. In [37] this is shown to be valid for all structures.

Using new certification laws and requirements for small and large helicopters [38] (jointly defined by U.S. and Europe) with respect to dynamic strength and damage tolerance, fiber composite structures can be proven safe and certified. Special properties such as thermal conductivity and electrical conductivity must be considered. For example, the pitch fiber has a thermal conductivity that is three times as high as that of copper (theoretically up to 2,400 W/(mK)). Thus, it becomes a candidate for the thermal management of components with high heat loads. Fiber composite structures are not subject to corrosion effects (for example, stress corrosion cracking), so they can be used to keep the cabin humidity climate pleasant for the passengers. The basic material properties must be carefully measured and described, poor specimen shapes for example, lead to premature fractures and increased scatter. The regulatory authorities then would react with the introduction of lower allowable strengths.

Innovation Demand The great potential of carbon fiber composites must more than ever be exploited in aircraft manufacturing! After the pace-setting developments in student gliding associations (Akafliegs) and in the industry there have been significant applications in gliders, helicopters, combat aircraft and satellites. In the early 1980s a vertical stabilizer in carbon composite was developed for the A300 configuration at Airbus Hamburg [39]. This was followed by the carbon fiber stabilizers for the A310 and A320 aircraft. This marks the first use of a large composite in civil aviation. The use of such stabilizers at all aircraft of these types is very successful. The crucial cost factor for the aircraft operators are the much larger inspection intervals compared with vertical stabilizers of metal construction. But only now, 30 years later, a further step in the composite design of large aircraft is done with the M400 and the A350.

Solution Consideration

• Design methods. In the design of composite structures, the damage tolerance requirements must be taken into account. In experiments, a residual strength, taking into account emerging humidity and maximum temperatures, must be demonstrated after the application of dynamic loads. Additionally, the impact of introduced damages is to be taken into account. Therefore, whenever possible, the modular structure with frames and stringers should be used, as this allows to limit the size of a damaged area. In a sandwich structure, however, local, unrecognized damage can lead to the ultimate failure under the applied load. Therefore it is necessary to limit the damage growth by a proper arrangement of stiffeners. Load transfer elements in fiber composites must be dimensioned accurately. Delaminations can result in significant damage. A "fail safe" design should be pursued in the load transmission. Loads in thick, curved fiber composite structures can produce badly transferable transverse stresses. Joints have great importance in fiber composite structures. Bonding, riveting and bolting are suitable joining devices that however need to be carefully dimensioned.

• Methods and Models for Structural Analysis The analytical methods for composite structures correspond to the methods used for metal structures. Optimization procedures are of great importance in the design of composite structures, since the design space is very large. In the calculations, the impact of thermal effects has to be taken in account (thermal expansion and thermal conductivity), as even the curing process produces additional stresses. A number of additional points must be considered when calculating composite structures. The application of fracture mechanics methods is of importance in particular for the determination of impact damage and delaminations.

These statements apply to monolithic structures. A complete composite aircraft structure includes a large number of joints and damping elements. The requirements for an improved definition and development methodology, Sub-Section 7.6, within the perspective of the Virtual Product, Sub-Section 7.7, demand an early and accurate determination of static and dynamic real-elastic properties, Sub-Section 7.10. This requires the development of structural-physical models that allow analytical methods to consider joints of all kinds, together with damping effects. For composite aircraft structures, however, this is less critical than for metallic structures.

• Manufacturing. A large number of manufacturing methods is used in the production of composite structures. In the early days of fiber composite technology dry fabric and fiberglass strands were wetted with resin and then coated as a wet structure. Air and excess resin was removed by suction and pressure. The quality of the structure was not very good, because an even distribution of the resin could not be guaranteed. To ensure accurate filling and a more even distribution of resin, pre-impregnated (mechanically resin-impregnated) "prepregs" were developed. Prepregs are still widely used in the preparation of high-quality structures. Their disadvantage is the high price due to the additional impregnation process. A drastic reduction of the manufacturing costs is essential. A saving of about 25 per cent can be achieved if one sets up a dry fiber structure, and then saturates it with resin using a vacuum infiltration process.

This manufacturing process is foreseen for use in large series and large aircraft structures. The assembly of carbon fiber composite structures with metals is only partially possible as corrosion problems may occur, especially in combination with aluminium.

Of increasing importance is the disposal or recycling of waste, or of no longer needed components. Here much more efforts are required. The recycling problem must be taken into account already in the design.

• General Recommendations

For future developments, the following recommendations are made:

1. The basic material properties for design and construction must be measured very accurately. High-quality sample forms must be standardized. Otherwise poorly designed and cheap sample shapes can raise certification issues. The consequently greater scatter and the reduced measured strength can lead to harmful reduction factors.

2. Bonding as a widespread joining method today is often described mathematically with an inadequate material behaviour. Suitable structure computation methods are available, see for example [40], but the availability of adequate material data constitutes a problem that must be solved.

3. The laws of the aircraft certification authorities today allow a sophisticated, application-oriented dimensioning with respect to "fatigue and damage tolerance". However, it lacks detailed requirements based on expertise. Application scenarios need to be developed in a coordinated effort of industry and certification boards.

4. The finite element method (FEM) is a good standard tool that is applicable to metallic and composite structures. However, extensions are urgently needed in order to take into account effects due to joints and damping elements,.

5. The numerical optimization is an important methodology in particular in the design of composite structures because of the many usable design parameters. For the optimization of composite structure topologies further developments are needed.

6. The exchange of knowledge is mandatory in order to avoid errors in the development and design of composite structures. At this time, however, a transparent exchange of knowledge generally is not given in Germany and Europe. Corrective measures to improve this situation are required.

7. Due to the variety of properties, fiber composites offer good opportunities to develop innovative structures. The variety of composite properties should much more be used than is the case so far.

8. Special additional computation methods are mandatory for the development of fiber composite structures. These concern the treatment of shock (impact loads) and environmental influences (temperature and humidity).

9. In terms of impact and additional damage inspection, methods need to be improved, in particular in relation to the static strength (compression after impact).

10. Repair methods have to be developed.

11. Using fixed strains – as for example 0.3 per cent – in the design of composite structures results in a too large global safety margin, and leads to over-dimensioning. The ultimate elongation for a unidirectional carbon fiber composite is, however, about 1.5 per cent. The relevance of using fixed allowable strains for all components must be stronger investigated than previously in order to fully exploit potentials of weight reduction.

12. Manufacturing methods for composite structures must be further developed to reduce the manufacturing costs.

7.10 Aeroelasticity

The Object Aeroelasticity encompasses the interactions (static and dynamic) of the air flow with the elastic aircraft structure. Individual aspects are:

- Deformation of the wing, including the high-lift system, and of the aerodynamic stabilizing and control surfaces under load.
- Flutter.
- Buffeting in its aeroelastic effect.
- Interactions between the elastic airframe and the flight control system (aeroservoelasticity, notch filter layout).
- Gust loads and fuselage vibrations (passenger comfort).
- Asymmetrical flow behaviour during low speed flight.
- Blade flutter in turbo engines, propeller blade flutter.

The real-elastic behaviour of the airframe, statically and dynamically, is governed by the mechanical stiffness of the components, but also by the damping and nonlinearities due to the joints (rivets, screws, bonds, ...), and possibly by post-buckling effects of structural components. In today's FEM simulations, the real-elastic effects, the structural damping, cannot be taken into account. The airframe and its components are monolithically modelled, although they are joined together.

Modern fiber structures are mostly monolithic or quasi-monolithic components, but usually not without joints at all. Here again the joining problematic, at least partially, returns. Damping elements are introduced in order to eliminate unwanted vibrations. The effect of damping elements must, of course, also be included in FEM simulations.

Innovation Demand FEM aeroelastic simulations can provide only the ideal-elastic behaviour, which leads, depending on the problem at hand, to inaccurate predictions in the definition phase and in the initial stages of development. The real-elastic properties of the airframe are found very late in the development phase by ground tests, the final ones only by the systems identification during the flight tests.

The consequences are:

- Data bases with limited accuracy for the systems simulations in the definition and development phases.
- Additional costs and structural weight due to the necessity of "repair solutions" in the late stages of the development process.
- Image loss and penalties for delayed entry into service by the customer.

An early and accurate determination of the real-elastic properties with respect to critical individual aspects is required, particularly for aircraft with highly elastic wings, for aircraft with artificial longitudinal stability, and for configurations with strong engine-airframe coupling (unconventional configurations, air-breathing super- and hypersonic aircraft). Mathematical models that describe the real-elastic behaviour are a prerequisite for numerical multidisciplinary simulation and optimization methods of the Virtual Product, Sub-Section 7.7.

Solution Consideration The recommendations only reflect the problem of the determination of the real-elastic properties of the airframe. It is absolutely necessary to have more knowledge of the physical properties of the airframe in the early product definition phases, Sub-Section 7.6 and the needs of the Virtual Product, Sub-Section 7.7.

The following aspects are mentioned:

- Systematic identification of critical airframe components and relevant simulation needs.

• Quantification of the deviations resulting from the comparison of the real-elastic properties from ground tests and ideal-elastic FEM simulations.
• Development of structure-physical models (statistical models based on parameter identification, direct numerical simulation, ...), see Sub-Section 7.9, for the mathematical description of the real-elastic behaviour.
• Structure-physics models for substitute airframe models in the early definition phases, see Sub-Section 7.7, depending on the structural detailing of the airframe.
• Systematic and comprehensive testing and validation of structural models with physical methods of multidisciplinary simulation and optimization (MDSO) on configurations of increasing complexity up to the complete airframe.

7.11 Flight Mechanics

The Object Subjects of flight mechanics are traditionally the flight performance of an aircraft according to the customer specifications (mission, payload, range, etc.) and the flight characteristics, which relate, among others, to the flight qualities of the aircraft with and without flight control system, including the stability characteristics. The flight characteristics include also the passenger comfort, for example in the seating area, the air conditioning, and the entertainment media. Flight performance and flight qualities are usually separate disciplines, but that finally must be seen closely coupled in the sense of the Virtual Product. An example is the flight with a rear center of gravity, which leads to a better flight performance, but results in poorer flight qualities.

Innovation Demand To solve the flight mechanics problems, it is necessary to know the basic forces, the total mass and the component masses of the aircraft, the engine thrust and the aerodynamic properties. As a general rule, it must be sought to reduce the aircraft mass, to improve the engine performance (less consumption), and to increase the lift combined with the least possible increase of the drag. In addition, new aircraft configurations have to be investigated, for example, with greater payload capacity, lower drag, etc.. In addition to improving the forces acting on the aircraft and optimizing the aircraft configuration, mission strategies have to be investigated, aiming at, for example, minimizing stratospheric flight, and flying fuel-saving flight segments (e.g., special area navigation with GPS on the landing approach).

Solution Consideration

A) Improvement of basic forces acting on the aircraft:
• Aerodynamics: a) Appropriate interference design that is as robust as possible over the entire speed range. b) Continuous landing flap setting for implementation of efficient landing approaches.
• Engines: a) Variable mixing of bypass air flow and core flow in jet engines in order to increase their efficiency. b) Improvement of propeller configurations which enable to fly at high speeds with acceptable efficiency. c) Use of modern high-performance engines (Diesel, Otto) to reduce fuel consumption.
• Mass: Use of hybrid materials (fiber composites, metal) in order to achieve weight reduction for a given strength and stiffness.
B) Increase of the safety of flight with less stable configurations (rear centre of gravity) by a fail-safe design integrating the existing capacity of the flight control system (usually many control loops are present), so that a failure of that system can be compensated.

7.12 Flight Guidance

The Object State-of-the-art flight guidance based on available electronic auxiliary systems (navigation, attitude, automatic system integration, ...) allows a very accurate and reliable, albeit more extensive integration into the cockpit. However, in the manmachine interface increasing attention must be paid to prevent possible overload/oversaturation of the pilot. The aircraft has to fly under optimal conditions from one point to another (fuel-efficient, safe, and in given time).

Innovation Demand Several, partly already existing or being under development, assistance systems deserve greater attention/priority. These include, for example:

- Improvement/optimisation of the ground-rolling guidance of aircraft, especially in bad weather (insufficient external visibility in fog, snow, rain) during day and night.
- Significantly improved wind shear detection during take-off and landing. Wind-shear detection systems are already effectively being used, but the warning is issued only when the aircraft detects the wind shear as a result of exceptional speed variations. A predictive detection and automated system response would bring a significant improvement of aviation safety.
- Optimization of the cockpit displays in order to improve situational awareness of the pilots. Here, the prevention of oversaturation of the pilot with information is of particular importance.
- From the airport infrastructure and systems independent take-off and landing aids up to instrumental landings on small airfields.

Solution Consideration

- Development of innovative systems for the automatic management/guidance of aircraft movement in reduced visibility on the ground, ground or airplane-based. For this purpose a centimetre-accurate GPS positioning could be used.
- Early wind-shear detection, already under development, must be promoted, and connected to an automatic evasive technique supported by the autopilot function. This would also significantly increase the passenger comfort in unusual situations (go-around and touch and go manoeuvres).
- Improvement of cockpit information particularly from the point of view that nowadays a plethora of digitally processed information is available, but only a relatively small amount of them is needed to be displayed, depending on the flight phase and the specific situation. Enhanced representation of the spatial environment can contribute significantly to a rectification of the today and in the future more heavily loaded airspace.
- Landings in strong cross wind with unpredictable gusts are still problematic. However, it must be sought, for instance by employing GPS, to increase the allowable wind components in order to enable a more flexible use of aircraft when strong wind conditions are predicted. Moreover, it would be useful to give a new look at the already sporadically applied landing gear solutions that allow a sideslip landing.

7.13 Avionics

The Object Avionics, in German language earlier called flight electronics, includes the aircraft-associated internal, as well as the mission-associated external, electronics on the plane. Each function is structured along its four elements that form a functional chain: Sensor – Processor – Effector – Relator.

The latter forms the necessary connections usually in the form of wires, but also of fields such as the electromagnetic field.

Innovation Demand The already extremely high standard of performance of computer technology – processors, memory and data buses – evolves continuously and requires no additional impetus by the aircraft industry. There are still many open requests, in particular on the sensor side, regarding, for instance, the visibility under bad weather conditions.

Displays are effectors. They link the human beings with their corresponding four elements – sense organs, nervous system, brain, limbs – to the technical systems avionics and aircraft. Here many wishes in terms of human engineering are still open. Research institutes of Human Engineering are required to determine quantitatively the mental load on the pilot in all phases of a flight mission. By means of information theory known from cybernetics, the mental load can be given in bits per second. The connection of avionic devices interconnected by bus systems – relators, such as fly-by-wire, fly-by-light – in terms of performance is largely covered.

Solution Concepts

• Realization of processor functions in the form of "hard-wiring“ as a quasi-analogue technology to prevent software (SW) errors. In the analogue technology the avoidance of errors is easier, as the once successfully tested system is determined by the reliability of its components. In the digital technology, however, generally unavoidable software errors are a permanent "threat". One hundred per cent secure software does not exist. A faulty SW module can – through the functional integration with other modules – bring to fail the entire system. In the past there were approaches to „cast“ vital functions directly into silicon. These approaches should actively be implemented in practical applications. The digital analogue then looks from the outside like an analogue block, which is wired in a conventional manner with others. Therefore it cannot propagate errors in the system through commonalities with other blocks.

• Infrared data transfer in the cockpit and cabin to avoid EMC problems. The cable system on the plane is an equally demanding and critical issue. Well known are the problems of the Airbus A 380. The so-called electromagnetic compatibility (EMC) remains a central problem as long as it is necessary to work with metallic conductors. Although the fiber-optic technology in this respect is a big step forward, it does not decrease the cost and the complexity of the wiring, which is a difficult topological problem, too. Irradiation of the passenger cabin by means of a modulated infrared radiator would eliminate the cabling and also the electromagnetic interference. Since the equipment of each passenger seat becomes stuffed with more and more IT functions, it can also react very flexibly to changes. In addition, the weight of the loom is saved, irrespective of the labour effort for installation.

If passenger acceptance could be achieved, the replacement of the cabin windows by computer monitors would bring significant savings of structural mass. For a realistic exterior view a minimum opening for a video camera is required at one place of the window. And the passenger could select other presentations on the monitor.

• Full screen "glass cockpit" with 3D display. The glass cockpit has now already reached a significant percentage of the cockpit design. Pilots, however, already complain about the overfeeding of information with too many functions, see Sub-Section 7.12. The previously described analysis of the load in bit/sec could be used as a criterion, what has to be displayed in each mission phase. Thus, at any given moment the entire relevant amount of information could be reduced to the minimum necessary. The 3D representation in use now in the entertainment media could further reduce the pilot’s stress with a simultaneous display of less significant information in the 3D background. This information may be presented only dimly or activated occasionally. This topic offers a wide field of experimentation.

• Optimization of the input media, for example, replacement of the side stick by video analysis of hand movements. Video cameras, which are used to control the pilot alertness, could also serve to recognize his movements by means of pattern recognition. Such a gesture as in the sign language of the deaf could eventually replace the use of the side stick. The side stick could remain, of course, physically available for any „just in case“ instance. By scanning the eye movement, the quality of the reading can be measured, using the residence time on a reading detail as a criterion.

• Sensor fusion of video, infrared and microwave images for permanent exterior view. The purely instrumental flight could be replaced by a synthetic visual flight through a sensor fusion of video, infrared, and microwave images. Digital terrain models in conjunction with GPS, Galileo, and GLONASS could be used for 3-D map display.

8 General Recommendations to Improve Competitiveness

The recommendations given below are of general nature, relating in particular to the aircraft industry and their established, but since a long time unquestioned structures and practices, particularly in the definition phases, but also in the development phases. The recommendations are aimed at increasing the competitiveness of the industry and are partly seen as being vitally important in the long run.

8.1 Exploiting the Potentials of Information Technologies in the Product Definition and Development

The structures of the product definition and development are different in the different parts of the aircraft industry. Common is the realization that in the early stages of product definition, the concept phase, or the preliminary design phase, the essential characteristics of the future product and thus large amounts of the economic budget (operating and life cycle costs), but also the ecological budget (operating and life cycle loads) are defined. In contrast to this finding, however, the early phases in general do not produce enough product knowledge, so that the risk of sub-optimal product solutions is large.

The solution concepts expressed in Sub-Section 7.6 relate to the technical procedures and the design tools. Crucial however is that in the practical experience a fundamental contradiction is present. Financial resources must be spent, even though the product is not yet sold. And this is one of the fundamental business risks to that the industry needs to be committed. If this risk is not sufficiently addressed, the danger looms of so called sub-optimal solutions.

The developments in information technologies, especially in numerical simulation and optimization (Virtual Product), Sub-Section 7.7, provide a possible opportunity to solve the above mentioned contradiction, if at the same time appropriate organizational and personnel measures are taken, but also the entrepreneurial risk-readiness is appropriately increased.

8.2 "Lessons Learned" for the Transfer of Product Knowledge

Typical of the aircraft industry, as compared to the automotive industry, are generally the long development times of the product. The targeted and accurate documentation and disclosure of person-bound knowledge – both in the company as within the whole field of aeronautics – should therefore have a much higher priority than it has today. (A detailed treatment of this problem and of the technology transfer to other sectors, which is very significant, would be beyond the scope of this document. Presentations of these topics can be found in [1, 41], as well as in the technical literature.) The documentation and disclosure is hampered by general industrial competition fears, and internally by profit-centre structures, see Sub-Section 8.6.

The basic condition for the transfer of knowledge are structured learning processes based on objective reviews at the end of a given product development, regardless of whether this has resulted in the realization of a successful product or not. Such reviews – "Lessons Learned" – largely do not take place in the industry. They could help to record positive and negative experience in a project. Good experience should be reflected in "best practice guidelines". Negative experience should above all motivate to identify errors, such as in the approaches taken in the definition and development phases, as well as to determine the appropriateness of the used simulation and optimization tools.

Four issues are raised here. First, in the product definition phase, the reasons for decisions for or against a possible solution usually are not adequately documented. This applies, secondly, also for problems (and their overcoming), which occur in the later product development phases due to insufficient knowledge created in the product definition phase. Thirdly and fourthly this is also true for problems (and their solutions) that occur later in the production phases and the operational life of the aircraft. Non-compliance with product guarantees and repair solutions are expensive and are generally covered by the reserve for contingencies.

In general, the transfer of the knowledge linked to an individual becomes a problem when employees retire. Despite of the insights the good intentions mostly fail because of the directly associated costs. This is usually also the reason why no assessment is carried out after the end of a project. Nevertheless it is important to ask whether "lessons learned" and an effective transfer of knowledge would not be cheaper in the long run than the usual approach. This holds in particular with regard to the technological risks which crop up again and again and the amount of the nowadays required reserves for contingencies. Graph-based design methods (Sub-Section 7.6) as computer-based processes in the definition and development phases, together with adequate numerical simulation and optimization methodologies (Virtual Product, Sub-Section 7.7) could be the right tools to speed up processes and take decisions rationally, without impairing the freedom of the designer.

8.3 Improving Knowledge Transfer via Conferences and Publications

Conferences and publications are important means of knowledge transfer. The European aeronautics and aerospace societies have gradually joined together in the Council of European Aerospace Societies (CEAS). With conferences, working groups and journals of the CEAS the transnational European exchange of information has been institutionalized. However, the national activities in the DGLR persist throughout. The European Rotorcraft Forum is dedicated annually to the helicopter technology. In Germany there are also activities such as the German Association for Fluid Mechanics STAB (originally "flows with separation"), which organizes biennial workshops and symposia. The symposia contributions are published in the Springer series "Notes on Numerical Fluid Mechanics and Multidisciplinary Design, NNFM".

However, it must be noted that at least in Germany in all of these activities the participation from the side of the industry in general is low, while it is good from the side of the universities and the DLR. The industry generally justifies this with costs arguments. But it must also be observed that often no activation of the employees is taking place. Moreover, some industry personnel may lack scientific expertise. The writing of a journal article or a conference paper is often perceived as an unreasonable imposition. This situation is of concern, because the transfer of knowledge in the field of aeronautics is still very important. A change of course is strongly recommended.

8.4 Introduction of a Post-Cayley Design Paradigm (First Aspect)?

The increasingly strong coupling of functions and subsystems in modern aircraft partly is of great importance. However, this coupling does not necessarily lead to a departure from the present approach, that is, to a post-Cayley design paradigm. This applies to the first aspect of the paradigm, as explained in Section 5. This statement is even more valid as the introduction of a post-Cayley design paradigm is associated with additional costs, organizational changes and high risks [17, 35]. However, it will become necessary to go that extra mile, because of the possible future development of highly elastic aircraft with artificially stabilized longitudinally motion. The rationale for this development is primarily environmental, but of course, also economical and global competition considerations play a large role. The post-Cayley design paradigm is primarily an issue of the industry, due to the associated use of the Virtual Product, but also a topic of research and teaching.

8.5 Potentials of Great Competitive Advantages through the "Second Mathematisation Wave"

About one hundred years ago, it was the intention of a Göttingen scientists circle, in the person of Felix Klein, to „mathematise" the until then substantially empirically determined sciences [1]. Klein won for the University of Göttingen the fluid mechanics scientist Ludwig Prandtl and the applied mathematician Carl Runge. Prandtl then promoted to a great extent the "mathematization" of fluid mechanics and aerodynamics, and also of other aerospace-related disciplines. If his work can be regarded as the first wave of mathematisation, the development of high-performance digital computer and information technologies since the 1980s brought to life the second wave of mathematisation in the technical and natural sciences. This second wave manifests itself in the numerical discretisation of methods for the solution of the governing systems of partial differential equations.

The second wave was never really addressed by the aircraft industry. That first of all should have been a task of the German Society for Aeronautics and Astronautics (DGLR) and also of the Society for Applied Mathematics and Mechanics (GAMM). In the aircraft industry, the new impulses of course were adopted, but essentially only on the discipline level. Examples are the finite element method (FEM), which has revolutionized structural mechanics, and later, when it became possible due to the enormous increase in computing power, the methods of – non-linear – numerical aerodynamics.

The information technology in the broad sense has also led to revolutionary developments, such as in computer-aided three-dimensional interactive design (CATIA: Computer-Aided Three-Dimensional Interactive Application), in experimental techniques, in product simulation methods, in avionics and so on.

The whole aircraft system is "simulated" mathematically during the definition and then the development processes. These simulations are performed initially with rather inaccurate data sets (low quantitative description of the aircraft in the early definition phases, Sub-Section 7.6). Later these data sets become increasingly more accurate. The simulation of the physical properties and functions of the aircraft and its subsystems with discrete numerical methods are used, but essentially only discipline-oriented, whereby the aerodynamic discipline usually has to solve the most demanding tasks.

The multidisciplinary simulation and optimization of the aircraft, which would be possible in the wake of the second mathematisation wave, see the Virtual Product, Sub-Section 7.7, has however not found entry into the aircraft design. This is surprising, since research as well as individual disciplines of industry have made great efforts and still make them to develop appropriate methods [35]. Some reasons for this are addressed in the following sub-sections. In any case, it is an urgent recommendation to identify the potential that results from the second mathematisation wave, and to exploit it in the industry.

8.6 Meaning of the Second Aspect of Cayley's Design Paradigm

In Section 5, the second aspect of Cayley's design paradigm has been introduced. It concerns the specialisation of the technical disciplines participating in the definition and development of the aircraft. This specialisation today characterizes the organisational structures of the aircraft industry, as well as the structures of aeronautical research and teaching at universities and colleges. The discipline specialisation is a bar to a more holistic approach.

In industry a technical discipline is usually housed in a dedicated organizational unit, which at the same time is a cost or profit centre. This leads to a demarcation and a competition with other organizational units, i.e., disciplines, because the cost centre must make a profit. The perception that cross-subsidies are harmful, enhances the effect. The result is a highly iterative operation mode in all product phases, in contrast to the repeated claims of the so-called concurrent engineering.

The approaches to modern numerical multidisciplinary methods are mostly worn by the aerodynamics, of course, with the involvement of other disciplines. However, the introduction of the new methods in the definition and development processes then fails because of the cost-centres aligned organisation, if the heads of organizational units have not enough incentives to work together with other organizational units other than in an iterative fashion.

As with today's products, this kind of organizational structure and the resulting operating methods appear to bring no disadvantages. Obviously, there is no need to change this modus operandi. Nevertheless, the interactions between the specific disciplines should be improved. If a post-Cayley design paradigm will be required for future products, it will be necessary to question the specialisation of disciplines and thus the current organizational structure (giving up the matrix structure in the traditional sense, in favour of project control by groups of individual disciplines that are networking together depending on the required interaction with each other). The introduction of information technologies in the industry has resulted in a reduction of staff in all disciplines. The introduction of, for instance, graph-based design methods, Sub-Section 8.2, together with elements of the Virtual Product will lead to a further reduction.

This provides an opportunity to overcome at least in part the disadvantages of the profit-centre structures by the merging of organizational units. The individual disciplines can then come up with appropriate multidisciplinary simulation and optimization methods to a weak level of iterative processes and thus to real concurrent engineering. This can also be the case even when Cayley's design paradigm (first aspect) remains essentially unchanged.

Another problem is the specialisation of the technical disciplines related to the definition and development of aircraft currently existing in higher education at universities and in independent research. External funding constraints faced by each institution and each chair position stand in the way of holistic research. Priority programs and collaborative research areas of the German Research Foundation (DFG) may lead to closer cooperation. The latter may prove ineffective, not least because of the understandable personal ambitions of the managerial staff.

8.7 The Issue Management Function and Technical Knowledge Should Always Be Reconsidered

A trend in the industry, which has given rise to concerns since a long time, is to consider technical expertise to be largely unnecessary for managers. This applies to line management functions, which correspond approximately to the head of department and above, but also for project managers. This view seems to be very common in partner countries, but also – in varying degrees – in Germany. If little or no innovation performance is expected in an organization unit, one can accept that.

But where innovation is required or for products with inherent high risks, this would be a wrong development. Insufficient insight – at least at head of department level – in the technical details, too strong commitment to delivery of cost centres-profits, schematic execution of processes, etc., would ultimately be harmful to the business. Also project managers should be not only budget managers but system integrators with both high-level, generic and low–level, specialized knowledge. Globally, it is recommended that all senior management positions are being held by qualified generalists.

Where this is not possible, the solution could be the introduction of a consistent professional career. Consistently in that the technical staff, at least upwards from the head of department level, should no longer be subject to their peers of the line management. In this way any conflict would then be escalated to development manager level. That would then have the potential to implement necessary technical measures and actions.

The technical hierarchy must never limit itself to a decorative function, especially at the direct working level. The best technical professionals must be the technical counterpart to the cost/profit-oriented line managers. It has been shown again and again that the line hierarchy strongly opposes such a differentiation. That then regularly leads to a softening or a trickling away of appropriate approaches. However, the shrinking of development budgets and teams in parts of industry naturally leads to a future shift-back of technical expertise into the management positions.

Existing professional career approaches in the industry are to be seen positively. However, their effectiveness needs to be checked again and again. The incentives for the parties must be considered in terms of their consistency under the ever changing boundary conditions.

8.8 Realignment of Industrie's Influence on Research?

An observation that is recommended to consider, is the strong influence that the industry, and that is essentially Airbus, today exerts on the direction of research. Here, the more short-term thinking of the industry is transferred to the research. This applies to the DLR, and to the universities, too.

Basically, a certain proximity of research to industry does no harm. It is bad however, if this leads – or even is taken as an excuse from the side of the research – to a position not to address long-term research topics. Also the pressure at the research institutions to acquire external funding has to be considered as harmful. Equally problematic is the third-party funding policy at the universities.

If third-party funded research predominates, then the topics covered are defined by the external donors and not necessarily those that would have to be worked on in view of future challenges.

One possibility to change this situation would be to dedicate to new and/or long-term topics a specific staff quota per research institution. However, then it must be avoided to deploy the strong performers for third-party funded research because this brings money, and to shift weaker performers to the "free" research.

About industrial research and development it must be noted that currently EADS obviously pursues very short-term targets for conversion into products. This is reflected even in research at universities and at the university-free research (DLR) influenced by industry. Of course, the cost overruns incurred in the past decades in several EADS projects, which were partially significantly higher than the estimated reserves of contingencies, must be "digested". However, the causes of these cost overruns were not only due to management errors, internal corporate structures and communication problems, but for some products due to insufficient technological preparation. This applies both to the hardware as well as to the process technologies.

8.9 Recommendations for Higher Education

Following a trend already observed in the U.S., the motivation of young people to take a technical profession is beginning to wear off in Europe, too. The motivation for technical professions must begin at school, if not even in the kindergarten. As it concerns the field of aeronautics, EADS, DLR, and BDLI have developed a very welcome set of activities. Tender offers and prices range from "Ideenflug" (EADS) and "Juri" (BDLI) to the well-endowed doctoral promotion price "Fly your ideas" (Airbus).

Higher education itself is primarily determined by the differentiation of the disciplines (second aspect of Cayley's design paradigm). It is questionable whether this is appropriate to the current degree for the future.

The requirement sometimes raised by the industry, to drive back the teaching of classical aircraft design in favour of other areas, such as the information sciences, must be rejected. It would even be appropriate to educate more students as aircraft design generalists.

On the other hand, the change in the definition and development methodology recommended in this document would also require a different course of training, as this is essentially based on numerical simulation and optimization methods (Virtual Product).

A training course "The Virtual Aircraft" could contain approximately:

1. Process technologies:
- disciplinary and multidisciplinary
    - physical modelling,
    - discrete numerical methods.
- information and communication technologies.

2. Product technologies (generalistic aspects of aircraft design and manufacturing).

3. System technologies (flight control system, avionics, ground systems, ...).

It is generally recommended to put more emphasis on experience and knowledge of university teachers in terms of the overall system "aircraft". Improving communication between universities and industry is essential, short-term thinking should not stay in the foreground. The teaching activity of industry members should be encouraged and not, as often now, merely tolerated.

9 Concluding Remarks

The German field of aeronautics – the aircraft industry, the university-free aircraft research and university teaching and research – is a worldwide recognized, and in many areas leading actor. With this memorandum, the Aeronautical Seniors Munich want to give suggestions, which they believe can strengthen in the future the economical and ecological power of this industrial field. The suggestions are directly based on the personal experience of the ASM members. The fact that they are partly critical is due to the individual experiences and concerns about the future correct positioning of the field of aeronautics.

10 The Members of the Aeronautical Seniors Munich, who have Contributed to this Memorandum

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