Gliding Research – An Important Incubator for the Entire Aviation

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Abstract

Written from a German perspective, but applicable world-wide, gliding research has contributed significantly to the progress in aviation; for example, development of composite structures and laminar flow. Since the beginning of gliding research at the dawn of the twentieth century, the research continues serving science, society and industry (1) as a generator of ideas, (2) as a platform for both experiments in many fields of technology and for fundamental and applied aerodynamic research and (3) as a provider for highly motivated offspring researchers and industry engineers for the entire aeronautical community. Major individuals and their contributions are identified as well as the contributions of the German academic flying groups.

Introduction

When I received the invitation of Loek Boermans to deliver the keynote address at the opening ceremony of the 29th OSTIV Congress, I really felt honored. After accepting the invitation, my proud feelings changed into uncertainty, because it was not clear what I could present in my talk that would not be boring. It was again Loek, who reminded me after quite a while, of course in his friendly and polite way, to name the final title of my presentation. What could I address to summarize, to some extent, my experiences during 38 years dealing with the specific subjects of OSTIV and aviation in general? So, in this talk I will attempt to bridge both areas, which is not difficult at all. Don't worry; I am not going to present a scientific lecture, like I usually do at the university. You better save your concentration for the more demanding presentations during the Congress. I am going to talk about two main issues, one concerns the role gliding research plays in the development of aviation and the other concerns the people involved and their motivations. Now, I will start with the first concern.

The role of gliding research

Gliding research takes a relatively small but efficient share in aviation research. It significantly contributes to the progress in aviation in many ways because, since its beginning at the dawn of the twentieth century, it keeps on serving science, society and industry

- as a generator of ideas,
- as a platform for both experiments in many fields of technology and for fundamental and applied aerodynamic research and
- as a provider for highly motivated offspring researchers and industry engineers for the entire aeronautical community.

Initially, I would like to address some examples in order to prove these allegations.

A first impression for the influence of gliding research can be obtained by looking at the agenda of this OSTIV Congress and the numerous fields which will be addressed over the coming days. Almost all the presented achievements and proposals will sooner or later find their way into aviation, in one form or another. We tend to focus on the more spectacular topics, which I am going to address later, yet it is important to realize that there are the many small pieces to the puzzle which make up the overall picture.

Technology transfer does not always take place directly, but in many cases it occurs in the long run. Individuals who worked on the solutions share their knowledge with friends and colleagues and make this knowledge an asset of their organizations where it is used directly or with modifications for similar applications. I do not know how the investigations on a safer winch launch for gliders or on new air data sensors presented at this Congress will finally affect aviation. Will it be the methods or the sensors, the developed software or the entire system, which we will find in the aircraft or air traffic systems of the future? Technology has become so complex, that even seemingly small achievements can receive a significant importance one day.

Let me name some other examples. The approaches for improvement of cockpit safety certainly will lead to common applicability. I wonder whether the impressive crash performance of today's Formula 1 racing cars is being considered in that work or whether gliding technology influenced the racing cars. The current state of composite fatigue research is also presented during this Congress. From a scientific stand point, it would be helpful if gliders had a much higher utilization, because there is still a lack of statistical data concerning the structural degradation of composites with time. Every detailed application of advanced computational fluid dynamics delivers a quantum of new knowledge, which helps to provide a more solid basis for the projects to come. Also, that does apply for experiences made in flight testing of new gliders. The lessons the aeronautical community learned from failures provided the necessary information to make aeronautics better, for example to improve flight safety. Not to forget about the contributions of meteorological research. Not only the glider competition pilots benefit from this research, but also the entire human community since we urgently need to better understand the complex mechanism and consequences of global warming. A mountain wave project, in which gliding was involved, resulted eventually in valuable findings concerning flight safety even of large commercial aircraft. If you are investigating the gliders dynamic flight following an optimized flight path through a scattered or aligned distribution of thermal up-drafts, you have to deal with the exact same problems that you have describing the consequences a small airliner has to expect when encountering wake vortices during a landing approach behind a larger one. Methods and results of that kind of research can be shared to the benefit of both sides. Finally, it is the sum of the single smaller steps which is ensuring sustainable progress. However, these smaller steps normally remain unseen by the public.

Let us, therefore, take a look at two areas in gliding research, which led to a significant improvement in aviation after World War II on a broader perspective. These areas include composites in loaded structure and laminar flow research. I ask for your understanding that I will focus on examples with specific German roots. I am doing that knowing that I am talking in front of an international audience.

Composites development

Modern commercial as well as military aircraft without composite structures are not anymore conceivable. That development was without any doubt initiated by glider research. It all started with the bold step of Eppler, Nagele and Lindner who created the "Phoenix" (Fig. 1), the first all-glass-fiber-composite glider. They wanted to make the best use of the potential performance gains laminar boundary layer sections were offering. As members of the Akaflieg Stuttgart, they relied on the help of an experienced student organization who managed to produce a glider in that then unknown technique. The success of that venture let to the first industrialized production of a glider, the "Phoebus" (Fig. 2). The glider was a derivative of the "Phoenix" and was produced at the Boelkow Company in Donauwoerth, Germany. Everybody in this audience most likely knows about the long lasting success the German glider industry saw since that point in time, which is based upon that initial step. Of course, other academic flying groups like the ones in Darmstadt and Brunswick were prepared at that time to follow that step immediately by creating gliders in short sequence like the D36 and the SB6, SB7 and SB8, respectively.

The everlasting race for improved performance in gliding required ever increasing aspect ratios and consequently stiffer wings. In order to prevent structurally thin high aspect ratio wings from flutter, which was the case with the glass-fiber composite wing of the SB9 (Fig. 3), the application of fibers with both better stiffness and strength became necessary. Consequently, another brave group of students from Brunswick had the heart to take the lead in tackling the, at that time, new carbon fiber and to create the first load carrying carbon fiber part of a glider: the centre wing of the largest glider at that time, the SB10 (Fig. 4). That constituted the start of an era in gliding which finds its impressive term in the gliders we can observe during the current world gliding championships in Lüsse. Application of almost 100% carbon fiber is now state-of-the-art, at least in the open class.

Also, the significantly growing experience in operating CFRP (carbon-fiber reinforced plastic) gliders improves the knowledge of both damage behavior and fatigue. Hybrid CFRP/AFRP (aramide-fiber reinforced plastics) laminates which provide for a superior protection of the pilot in case of a crash is also state-of-the-art in gliding. Commercial aircraft are more and more employing that technology, however in different material combinations like in GLARE, a glass fiber-aluminum composite which combines the advantages of fiber reinforced plastics with the superior impact resistance of metal.

The introduction of a new technology takes a lot of time and money in military and commercial aviation, thus the development seems to progress relatively slowly. For a long time, it was not clear what the state-of-the-art was with respect to the military application of CFRP's. Now we know that "all composite" aircraft have been build since the 1980's. However, on the commercial side, the substitution of metals in load carrying structures happened in a more evolutionary process. After the introduction of CFRP empennages and engine cowlings it took a while until floor beams became composite parts. Except the ATR72 (Fig. 5), there is no commercial aircraft flying with an all-carbon wing. Now we see the outer part of the A380-wing and its mid-section as well as a prospective all-composite fuselage incorporated in the B787 (Fig. 6). All that took 36 years since the maiden flight of the SB10. That long period can be justified by two facts. One is the strict certification requirements for commercial aircraft and the second is the huge financial burden of today's aircraft programs, which exceed, as we learned from the A380, 12 billion €. Whereas the operational and certification requirements for a glider are relatively moderate, an airliner structure has to sustain harsh environmental conditions and the provision of evidence for both a damage tolerant structure and the repair procedures, therefore, is much more demanding, costly and time consuming.

I think that, without the innovative attitude of the academic flying groups, their boldness and their capabilities, we would not see commercial aircraft employing today composites in more than 60% of their structure in terms of mass. Together with a highly innovative glider industry, which took the risk of adopting the new developments of the groups immediately, the groups created the prerequisites for a successful technology transfer into commercial aviation.

The technology transfer from research to industry seems to be functioning in gliding much better than in other areas. Astonishingly and in contrast to most of the other areas, the transfer functions predominantly without any public subsidies. By accumulating operational experience over a long period, that knowledge transfer laid the foundation for one part of the economical success of aviation.

Laminarization research

I must admit, that I am a little reluctant when talking about the second field which is the laminar flow research. The reason for that is somewhat influenced by my personal jealousy of the tremendous funds that scientific area has obtained since its first steps in the 1940's. Since Prandtl formulated the boundary layer theory, it is well known that a laminar boundary layer flow has much less drag compared with a turbulent one. We know about the potential of laminarization, but still we neither have a laminar wing on an airliner nor on a military aircraft. That knowledge, of course, has been the major driver for the development of a large number of efficient airfoils which created the basis for the high performance of today's gliders.

The development of laminar airfoils was initially based on the availability of new inverse design methods, which allowed calculating a section shape to a specified pressure distribution. A long laminar running length requires a late and strong pressure recovery, which however stands in conflict with the separation sensitivity of a laminar boundary layer. A lot of fine tuning was necessary to create a section which finally featured a low drag thereby being also sufficiently in-sensitive to contamination. Achievements from that research inseminated non-aeronautical fields immediately, including the design of wind mills and the lateral plan elements of sailing yachts.

Parallel with natural laminar flow research, new boundary layer control techniques have been developed and scrutinized. To name only some of them:

- Transition strips as surface treatment for a defined transition
- Boundary layer suction for artificial laminarization
- Dynamic blow-out jetting for laminar flow separation control
- Static blow-out jetting for turbulent boundary layer separation control
- Stabilization of Tolmien-Schlichting waves by phase shifted acoustic waves

Of course, the testing of some of these methods needs to be accomplished using robust in-flight sensors which have to be developed:

- Infra-red thermography,
- Pressure sensitive coatings,
- Piezo arrays

to name just a few of them.

When I was actively soaring about 15 years ago, pilots were pleased to fly standard gliders with a maximum L/D of approximately 38 and in open class the SB10 set the pace with a figure of approximately 51. It was clear to all of us at that point in time, that, in light of the tremendous progress in cruise speed which came along with laminar airfoils and carbon wings, another quantum leap would be unlikely and that we had to look forward to a decline in future achievements. We were, like so many prophets, absolutely wrong with our predictions for technology development and also for our assessment of human ingenuity. It seems to be a typical error of people in the mid-term of their active life; they are especially prone to underestimating the capabilities of their successors. Statistically, L/D is still constantly increasing over the decades since the beginning of gliding (Fig. 7). So far the leading edge design, the fabulous “ETA“ of Reiner Kickert (Fig. 8), must also be seen as an intermediate step in a long series of gliders to come with even better performance. I hope, that the currently ongoing production of the “Concordia” (Fig. 9). which was designed by a team led by Dick Butler in Tullahoma TN USA, will live up to the expectations. With an even higher aspect ratio than the “ETA” it will probably prove the linear L/D trend.

Boundary layer control research in gliding initially started with just the opposite of laminarization. The late transition on the lower surface caused, in practice, the emergence of separation bubbles and subsequent drag increase at high speed. The solution is well known by the modern pilot: turbulence tapes take care of a defined transition before the potential separation point. Fundamental investigations on locating the transition area have been conducted using gliders (Fig. 10). Blow-out systems also performed well for turbulent boundary layer separation prevention; however their efficiency with respect to the benefit-to-effort ratio proved to be limited. Also boundary layer suction has been investigated for both laminarization and separation control for glider wings (Fig. 11). The results of recent research in Delft and in Stuttgart again are proving that the principle of suction is functioning well in both aspects and the overall potential for improvement of glider performance and is at least theoretically impressive. Ideas for the integration of suction systems in gliders are also well advanced (Fig. 12). For the application on a real glider, the required energy for the pumps will probably be provided by solar technology. Current research at the TU Berlin is also focusing on the suppression of Tolmien-Schlichting disturbances within the laminar boundary layer by means of out-of-phase acoustical excitation. That work includes the design of a control loop and the determination of the control laws (Fig. 13).

A lot of public money has been spend in the meantime in Europe and the US to learn more about the intrinsically hidden secrets of boundary layer control which prevent the aeronautic community to convert the well known phenomena into a realizable and eventually beneficial technique. Systems feasibility in wind tunnel and flight test has been proved in the scope of the expensive European funded European Laminar Flow Investigation (ELFIN) program (Fig. 14). A fin of an A320 has been chosen as a successful first attempt to prove hybrid laminar flow in flight, because it promised to be feasible with the available technology. However, the systems to support that artificial laminarization turned out to be too large, too costly, too loud and too sensitive for direct applicability. Besides, the same result has been achieved by Boeing with a wing suction system applied on a B757 in the early 1990's. The state of basic research has progressed far. However, the way towards a practicable solution for the everyday use still seems to be far off. Another large sum of funding has been recently released to foster laminar wing research in Europe.

Technology transfer in the field of section aerodynamics from gliding to commercial aviation is much more difficult compared to composites. The reason is found in the different Reynolds and, essentially, Mach number domains of both applications. A rearmost pressure minimum at the upper surface is good for long laminar boundary layer running length and, thus, minimum drag. However, shock induced separation will be, thereby, assisted simultaneously. It requires another precise fine-tuning of the airfoil's shape in the super-critical Mach number domain. Improvement of natural laminarization and prevention of buffet at high speed are conflicting criteria. The conflict will not be solved by answers gliding research can provide alone.

However, for gliding scientists there may be new hope on the horizon. Looking at today's high and soaring fuel prices, aircraft of the future will certainly look more like gliders. The wing aspect ratio has to be increased significantly while decreasing wing loading and sweep in order to fly more economically at lower speeds far from the buffet boundary. Additionally, such configurations allow the use of advanced propellers with their specific low fuel consumption, a view shared more and more by industry representatives today. If that is the future, the achievements of gliding research will be more applicable to commercial aviation.

A similar situation can be observed looking at special purpose high altitude, long-endurance aircraft like the Burt Rutan designed "Proteus" and the around-the-globe aircraft "Voyager" (Fig. 15). Their wings illustrate their true origin in glider wings, although their configurations exhibit their own signature. Voyager's successor, "Global Challenger" (Fig. 16), has even more similarity with today's high performance glider. Also, the emerging wave of unmanned aeronautical vehicles (UAV) in military and civil use are obviously benefiting from the achievements of gliding research (e.g. "Global Hawk", Fig. 17).

Who are the people?

Being a German native, I am asking for your understanding that I will primarily focus on Germans when I now talk about individuals in gliding research. I would like to share with you my personal perception of the people involved in gliding research and will start with a quotation of Saint Exupéry, the engineer-poet (Fig. 18). Please accept my free translation of it. "If you want to build a ship, don't drum up the men to gather wood, divide the work and give orders. Instead, teach them to yearn for the vast and endless sea." Like in maritime navigation, also in aviation, there seems something emotional to be involved.

Maybe it is the challenge to work with overwhelmingly strong natural elements, which could eventually jeopardize or even destroy one's own existence. In aeronautics, the sources for these emotions are numerous. For an engineer, it could be the success or the failure of a project or the unexpectedly good airplane performance. A pilot may experience the risk of a maiden flight or a wonderful flight experience, a successful marginal long final approach in a glider, the encounter of bad weather, the escaping from a dangerous situation or a wrong strategic decision in a gliding competition.

In my industrial career, which included, amongst others, 15 years working for an airline, I was constantly encountering these kinds of emotions as well, which happened almost to everybody in any department in a wider sense. When I talked with colleagues in the airline industry, I was always impressed about the mutual understanding of being involved in something special and important which results in a certain kind of pride. The pride not only affects engineers like me, but everyone in aviation. I think that somehow everybody in this field shares the same basic idea which defines a specific community. If you are traveling around the globe, you will find that community everywhere. The community of people who decided to interest themselves in aviation, in aeronautical research or even in gliding shares the mutual interest in human flight.

Like it was in the past, it is today and will likely be in the future. Progress in gliding research is primarily the achievement of individuals, working in different environments that may be

- Interested individuals with different backgrounds,
- Members of the academic flying clubs, in Germany called AKAFLIEG, which are organized in the umbrella organization called IDAFLIEG,
- Members of the various aero-clubs,
- Scientists at universities and research organizations or
- Engineers in the industry.

The list of individuals is too long to mention even the renowned names; however, I would like to address at least a few of them.

It is not possible to not mention of Otto Lilienthal (Fig. 19), who, with no doubt, can be quoted as the first glider pilot who also accomplished fundamental scientific research with groundbreaking results for the development of aviation as it is today. That is certainly well known to you. His book "Der Vogelflug als Grundlage der Fliegekunst" gives evidence for his ingenuity. However, it may not be known that he also contributed knowledge to society in a broader context. He held patents for a hot-air motor, mining machinery, a efficient steam generator based on a mesh of meandering pipes in a vessel and the first building block toy system ever. In his factory, he introduced employee involvement as a matter of course, which included the share of 25% of the yield, as a means to ensure good motivation, a feature which seems not always known by a variety of managers of today's large companies. Like the father of modern flight theory, Sir George Cayley (Fig. 20), he was already aware of the potential of a future aviation in supporting global peace by a better mutual understanding, because it gets people closer to each other.

It makes me proud that Otto Lilienthal studied mechanical engineering at the predecessor institute of my university, the Berlin University of Technology. At that time even the founder of the science of mechanical engineering, Franz Reuleaux (Fig. 21), did not succeed in capturing him as a scientific assistant. I am wondering what the reason was, but that reminds me of the difficulties a modern, low-financed university is facing to attract capable young graduates in light of the current market situation for engineers and the poor wages the university can offer. I think he felt at that point in time what he repeatedly argued during his entire lifetime: sustainable progress is always based upon both, theoretical knowledge and practical experience. Although Otto Lilienthal will always keep the privilege of being the first, he was not the only one.

One breakthrough in sailplane development at that time has surely been achieved by the three constructors Haase, Kensche and Schmetz who designed and produced the high performance glider HKS 1 (Fig. 22) with 19m span which employed a just created laminar wing section of the NACA 64-series which required an all-new wing structure. Because surface stiffness was not just necessary in front of the spar, but to the trailing edge, they covered the entire wing with plywood. Their solution paved the way for a much better drag awareness, which took a closer look on boundary layer transition aspects and, thus, for the birth of today's smooth surfaced gliders made of composites. As I already mentioned Eppler, Nagele and Lindner took the ball, which was pushed by the HKS 1 and introduced the Phoenix, which enabled them to improve the aerodynamic performance significantly and, as I mentioned in the beginning, opened the doors for the structural realization of today's high aspect ratios.

With the kick-off for a new wing section-design philosophy, which involved natural laminar flow thorough experimental and theoretical aerodynamic research, the gliders overall performance significantly improved. There are a couple of individuals who must be mentioned when talking about the development of the current low drag, less disturbance-sensitive wing sections: Wortmann/Althaus, Horstmann/Quast, Eppler and Loek Boermans, the current OSTIV president. By their contributions, they made the entire gliding community aware of the necessary cleanliness of the surfaces in order to utilize the gains, which remain theoretical, if the wing leading edge is not covered with dead flies or dust.

Some people of the first hour found their way through the industry thereby making great use of their experience with carbon fiber technology they earned from glider development. Just to name Juergen Klenner as one representative of my generation; he was responsible for the SB11 development at the academic flying group Brunswick. After that he was involved in the development of the carbon fiber fuselage of the Eurofighter in a leading role and later took responsibility for the development of the entire Airbus aircraft structure.

I don't want to conclude this chapter without once more mentioning Burt Rutan as another groundbreaking individual. After delivering a long list of successful aircraft designs, he, together with a relatively small company on his side, now counters one of the world largest research institutions, the NASA, with his impressive Spaceship One (Fig. 23). I am addressing this because that sub-orbital air vehicle is a true glider and the configuration of the launch aircraft "White Knight" (Fig. 24) exhibits the typical features of a glider as well. Besides, the Spaceship One has been certified by the FAA as a non-self-launching motor glider. Isn't that another prospective field for OSTIV? The enterprise is so fascinating due to the fact that their success is solely based upon personal motivation and enthusiasm and on private money. Again, like with most of the people involved in gliding research personal engagement is the key for the tremendous success.

The exceptional role of the academic flying groups

Getting closer to the end of my talk, I will say some words about the exceptional role of the academic flying groups in Germany. Almost in all the examples I address, they left more or less their own unique mark. The ones in the groups, who took a leading role in the projects development, later-on evolved as capable and well known engineers to which today's glider industry owes its strength.

As a student advisor, I am frequently asked about the value of an elongated academic study due to an engagement in the AKAFLIEG (Fig. 25), taking into consideration aspects like the public perception of an unduly long study and the current large demand for engineers in the industry which is creating excellent job opportunities. My answer for them has something to do with my personal experience as a former long-term member of one of the groups. There are three major arguments I deem important, all of which are concerned with a conscious handling of lifetime. Because in school you are bound by the order of your parents and teachers and after studying you are bound by your boss, it would be a sign of intelligence if you made use of the unique freedom of choice you have as a student. However, you have to use the time efficiently dealing with everything that you can personally benefit from, e. g. something you are highly interested in. Personal development and soft skills are, from my point of view, of equal importance like academic achievements for the professional life. An engagement in one of the academic flying groups, therefore, is a good investment into one's own education although it does not count in terms of credit points. There is no doubt that practical experience along with experience in project management and soft skills, learned by real life exposure to the psychological tensions in a team of colleagues, are fundamental capabilities of an engineer. The introduction of tuition fees, study time restrictions and the recent transition to bachelor/master schemes with the associated more demanding curricula are the reason for existence problems the academic flying groups are facing today. I am afraid that an important, innovative and efficient partner in gliding research, therefore, is likely going to leave the stage on the long term.

For me there is absolutely no doubt that there will always be young people who ask the right questions and work hard on answering them. The exciting experience of gliding will keep its role as an efficient motivator for them and, thus, keep its role as a scientific incubator for the entire aviation.

Concluding remarks

I would like to wish all of you exciting days with interesting and stimulating presentations in the 29th OSTIV Congress. Additionally, I would like to encourage those, who are not yet affected by the virus called gliding, to immediately take the first step and register in one of the flying schools you will find all over the world. Your own flying experience will help theorists to understand their science better and enable them, as I hopefully could communicate, to promote aviation.

Figure 1 Phoenix, 1957.

Figure 2 Boelkow Phoebus, 1970.

Figure 3 SB 9, 1969.

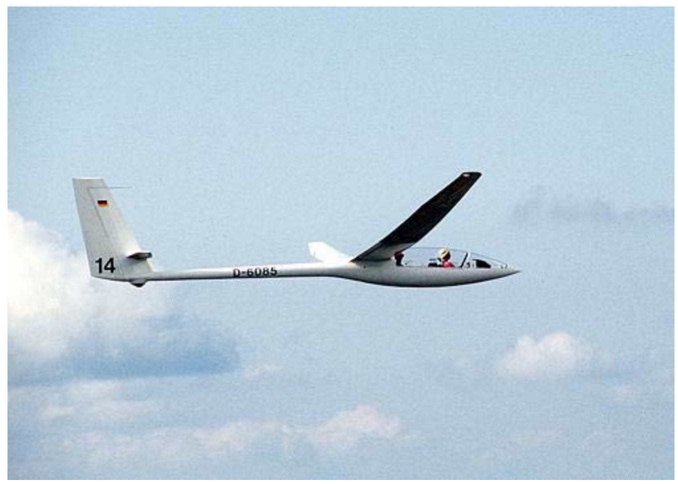

Figure 4 SB10, 1972.

Figure 5 ATR 72, 1989.

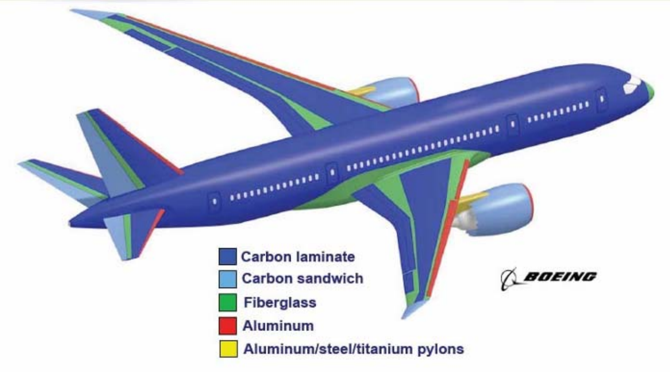

Figure 6 B787 – Materials.

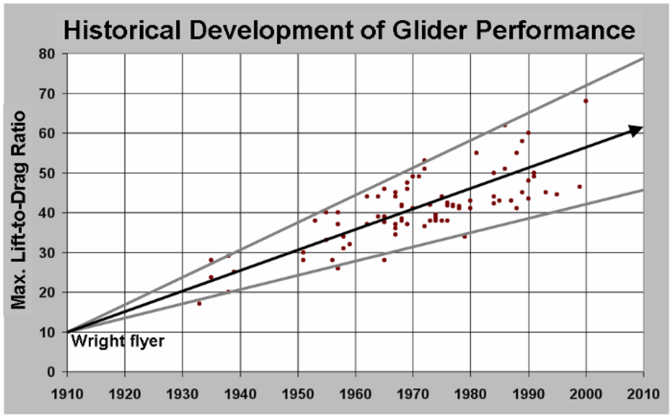

Figure 7 Historical glider performance development.

Figure 8 ETA, 2000.

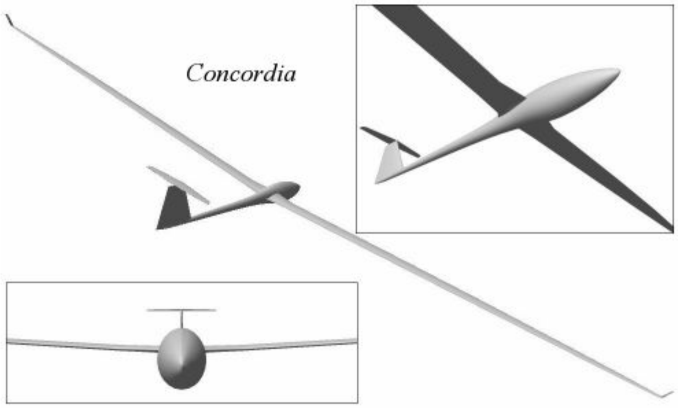

Figure 9 „Concordia“ project, Dick Buttler, Tullahoma, TN USA

Figure 10 Laminar wing research at TU Berlin.

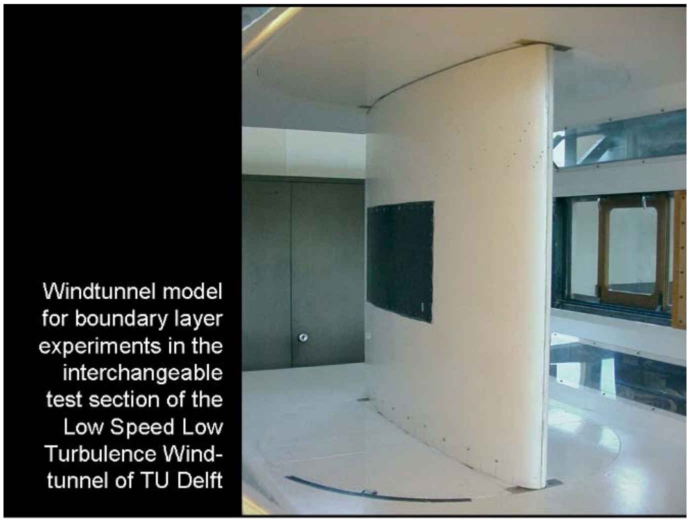

Figure 11 Laminar wing research at TU Delft.

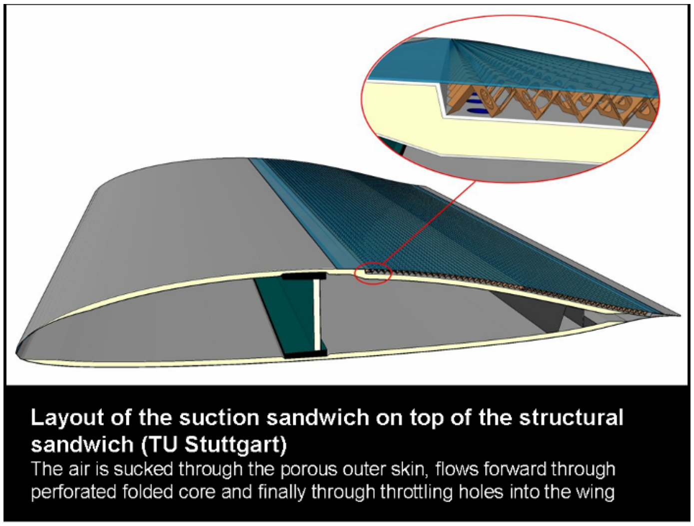

Figure 12 Laminar wing research at TU Delft and TU Stuttgart. The sandwich structure has been developed and tested by TU Delft. TU Stuttgart provided and perforated the folded core, their specialty.

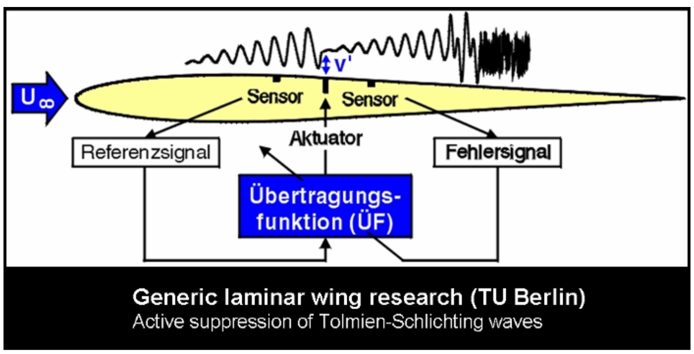

Figure 13 Laminar wing research at TU Berlin.

Figure 14 European funded laminar wing research.

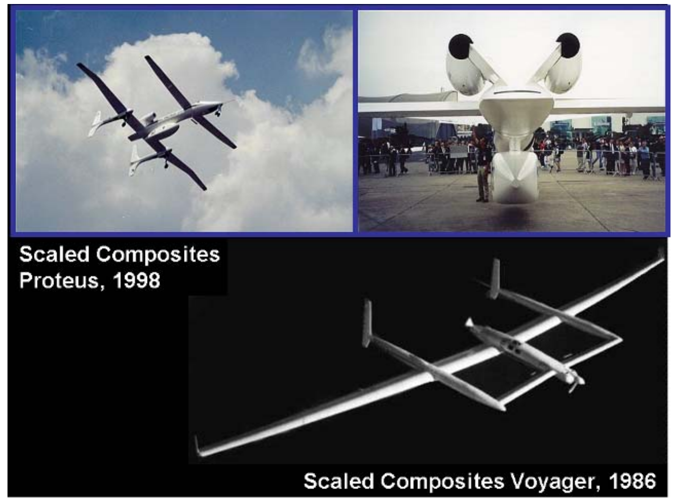

Figure 15 Scaled Composites – Burt Rutan designs.

Figure 16 Virgin Atlantic Global Challenger, 2005.

Figure 17 Boeing Global Hawk, 1998.

Figure 18 Antoine de Saint Exupéry, 1900 - 1944.

Figure 19 Otto Lilienthal, 1848 - 1896.

Figure 20 Sir George Cayley, 1773 - 1857.

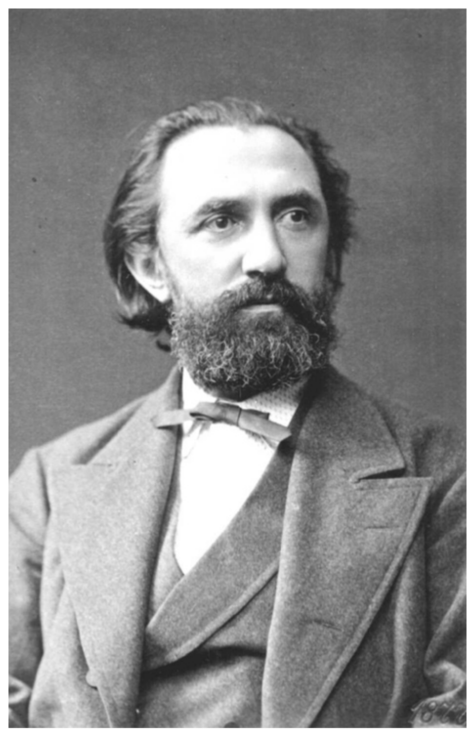

Figure 21 Franz Reuleaux, 1829 - 1905.

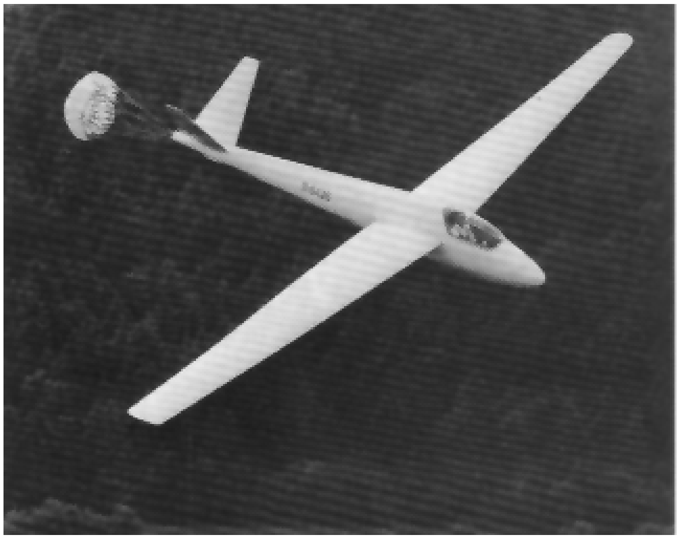

Figure 22 HKS 1, 1950.

Figure 24 Burt Rutan, White Knight, 2004.

Figure 23 Burt Rutan, Spaceship One, 2003.

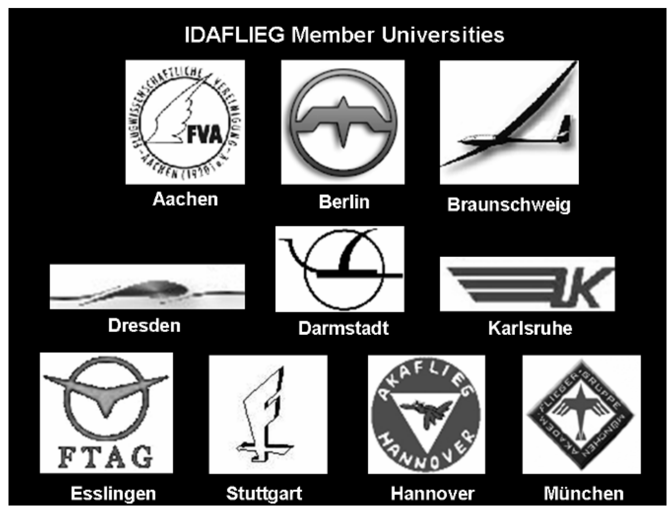

Figure 25 IDAFLIEG member universities.