TITLE: A Concept of a Shapevariable Fowler Flap on Transport Aircraft

A Concept of a Shapevariable Fowler Flap on Transport Aircraft

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ABSTRACT

This paper presents a part of the major project "Adaptive Wing (ADIF)" of the partners German Aerospace Center (DLR), DaimlerChrysler Research, and DaimlerChrysler Aerospace Airbus. Using the Airbus A330/340 fowlerflap as an example, the objective of this project is to show, how the high lift behavior of modern transport aircraft can be improved by intelligent structural concepts, without negative effects on cruise flight. Even an improvement in transonic flight is possible. For this, a combination of passive and active measures is necessary, as the following paper shows.

INTRODUCTION

Wings of modern transport aircraft are optimized for cruise flight. They have a transonic wing profile with the best lift/drag ratio at high speed. For flights at low speed this type of profile is inapplicable. Therefore, the required additional lift for take off and landing is achieved by using high lift devices, such as slats at the leading edge of the wing and flaps at the trailing edge [1]. In cruise configuration slats and flaps are retracted. A special type of a high lift device is the fowler flap, used in the Airbus A330/340. The lift increasing effect of this flap is based on enlarging the wing area, increasing the airfoil camber, and accelerating the airflow within the gap between wing and extended flap (**Fig. 1**).

The fowler flap used in the Airbus A340 has some disadvantages. Due to the elasticity of the carbon fiber, of which the flap skin is made, the trailing edge of the flap deforms when airload is applied. These deformations lead to higher drag during cruise flight, which means that the efficiency of the airplane is decreasing. Another disadvantage is the necessity of three flaptracks, which means higher weight, higher complexity, and higher costs, compared to a bedding on only two tracks. The middle track is used to force the elastic line of the flap into the same shape as the elastic line of the wing in this region. Matching elastic lines are necessary for the proper shape of the gap between wing and flap. The acceleration of the air inside the gap is based on the nozzle effect. If the gap is too wide, there will be no adequate acceleration. On the other hand, if the gap is too narrow, it will be plugged up with boundary layer which means, that no air from the lower side of the wing can go through the gap to the upper side. In both cases there is no adequate energy enrichment of the airflow on the upper side of the wing, which leads to flow separation. The lower lift due to separation can not be accepted in a part of the flight, when every percent of lift is needed. This means, that the size of the gap is crucial to the efficiency of the flap and finally to the whole high lift behavior of the aircraft.

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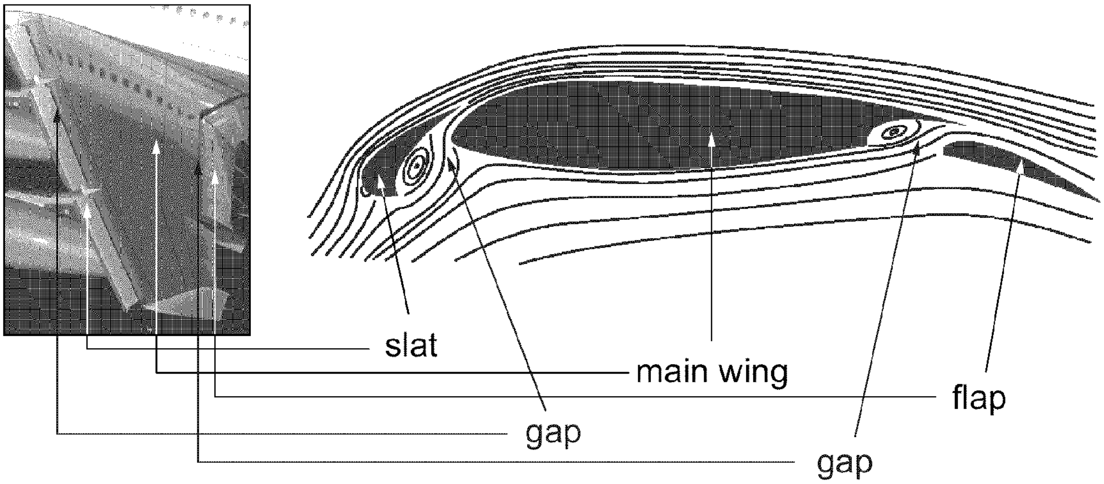

Figure 1: Airfoil with extended slat and flap

OBJECTIVES OF THE PROJECT

The topic "Shapevariable Fowler Flap", part of the major project "Adaptive Wing (ADIF)" of the partners German Aerospace Center (DLR), Daimler-Chrysler Research, and DaimlerChrysler Aerospace Airbus has the objective to decrease drag, complexity, weight and costs. To realize this, the flap track number at the A340 will be reduced from three to two. Therefore, a totally new design of the flap due to the required higher stiffness in spanwise direction is unavoidable. In the course of this redesign it is possible to gain a better control of the gapshape, in order to improve the high lift behavior. To realize this, passive means, such as the optimization of the stiffness distribution and track positions, pre-deformation, and aeroelastic tailoring as well as active means like the integration of an actuator into the flap is necessary.

One positive effect of the higher flap stiffness is the decrease in deformations at the flaps trailing edge during cruise flight, leading to lower drag. With the structurally integrated actuator it is possible to reduce vibrations, induced by external loads. Furthermore, the additional loading of the wing due to the middle flap track disappears, the desired elastic line of the flap is accomplished with flap-internal constraints (e.g. actuators).

REDESIGN OF THE FOWLER FLAP

The redesign of the Airbus A340 fowler flap, bedded on two flaptracks is performed in the following steps:

1. Identification of the crucial load cases.
2. Determination of the wings elastic line as a reference for the elastic line of the flap.
3. Determination of the track position combination with minimal flap deformation using a simple beam model.

4. Calculation of the required stiffness distribution leading to the desired flap deformation with applied airload.
5. Design of a structurally integrated actuator allowing an adaptation of the elastic lines.
6. Transfer of the determined stiffness distribution from the beam model to the real flap using a parametric finite element model of the fowler flap including spars, ribs, stringers, and tailored skin. Pre-deformation, aeroelastic tailoring and the integrated actuator are considered.
7. Detailed design of critical parts, e.g. spar/actuator interface with an extremely high stiffness.
8. Examination of the dynamic behavior of the flap with integrated actuator.

To show, how the redesign actually is made, all the above mentioned steps are given in detail below.

There are some hundred loadcases at the design phase. For the preliminary design of the two-track-flap it is impossible and needless to consider all of them. Instead, the four dimensioning loadcases were chosen [2].

In loadcase RS1 the cruise load is applied and the flap is retracted. This loadcase is essential for the cruise flight stiffness design. The other loadcase with a retracted flap is R2. In this loadcase the recovery after an emergency dive is considered. With the highest possible airload this loadcase is used for the strength design of the flap. At the remaining two loadcases S26 and S32 the flap is extended with 26° and 32°. At these loadcases the stiffness design, crucial for the gapshape, is performed. With these four loadcases the main part of the flight envelope is considered, enough for a preliminary design.

The elastic line of the wing is the reference for the calculation of the flap stiffness. Both elastic lines have to match tightly, in order to guarantee a constant gap size. With a known reference line and known airloads it is possible to calculate the necessary flap stiffness for all four loadcases. The elastic line of the wing (reference line) is calculated with local deformations at the flaptracks and the spoiler hinge line. Due to the wing sweep there is a bending-torsion-coupling **(Fig. 2)**, that has to be considered. This coupling leads to the necessity of aligning the flap stiffness axis in a certain angle to the spanwise direction, known as aeroelastic tailoring[3,4,5]. With this measure it is possible to make sure, that there are no gaps between inner and outer flap and between flap and aileron.

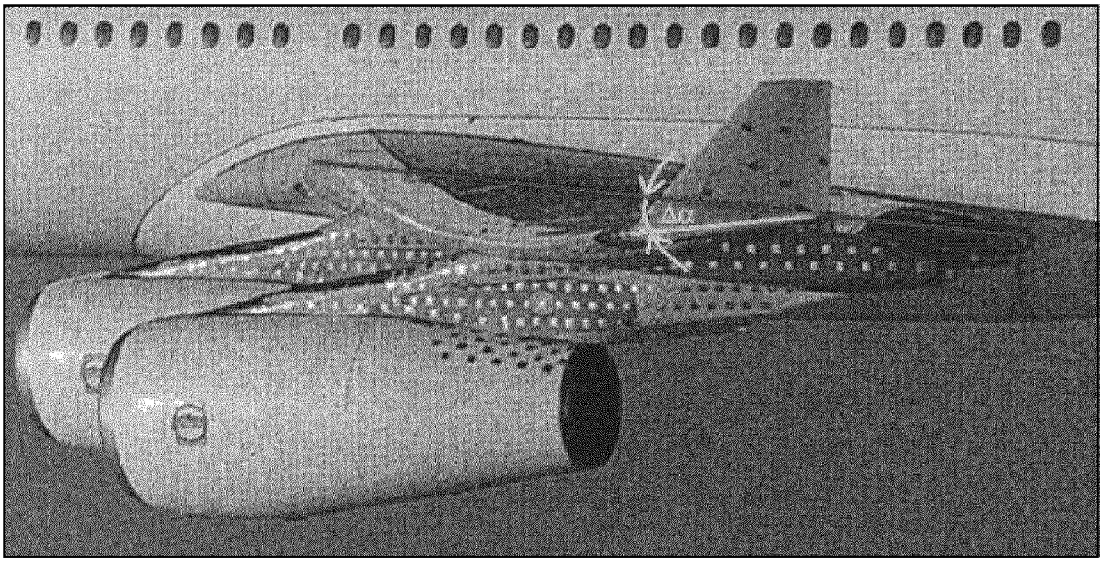

Figure 2: Elastic line of the wing

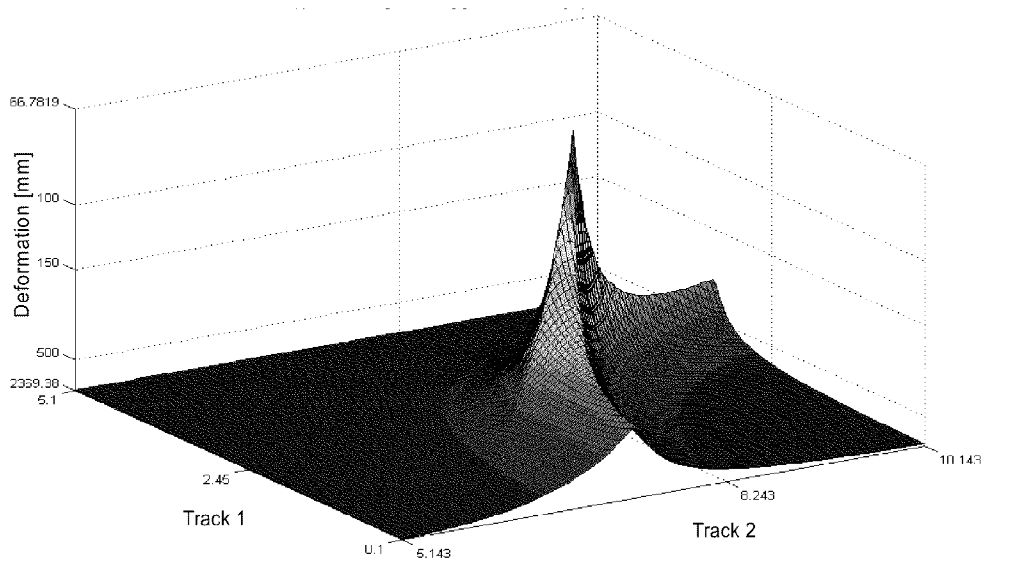

Figure 3: Optimization of the flaptrack positions

The determination of the best track positions is extremely important for the deformation of the flap. **Fig. 3** shows, that there is a difference of approximately 3500% in flap deformation between the best and worst track positions. For the track position calculations the stiffness distribution of the original flap was used.

The integration matrix method and a beam model of the flap was used for steps 3, 4, and 5 of the redesign. There are some advantages of this method, compared with a complex FE-model [6]. First of all, the calculation time is much lower, making parameter studies possible. Loop programming for a stiffness optimization is very simple. A big advantage of this method is the possibility to integrate an actuator into the model. It is possible to load the beam with a single actuator force or an active bending moment distribution. That makes it easy to see, how an actuator can influence the elastic line of the flap.

With the determined optimum track positions for all four loadcases it is possible to calculate the required stiffness distributions in order to achieve the desired elastic lines.

There is a difference in the four stiffness distributions, due to the different loads and reference lines. Therefore, the chosen passive flap stiffness can only be a compromise with special attention to the extended flap loadcases.

The adaptation between the elastic lines at different loadcases can only be achieved with an active adaptation of the stiffness distributions. Therefore, an actuator has to be integrated into the loadpath of the structure. Two different types of actuators are possible–a discrete actuator for a discrete active moment or a distributed actuator [7]. Both actuator types have advantages and disadvantages.

A distributed actuator can be integrated into the skin of the flap. The advantage is, that there is no necessity for a special load introduction due to the distributed load. This type of actuation is the most efficient one. Unfortunately there are some critical disadvantages. The most important problem is the capability of the present array-actuators (e.g. PVDF) to withstand the applied loads (forces, moments, and temperatures) and their amount of active deformations. Another problem is the integration into the skin without forcing delaminations.

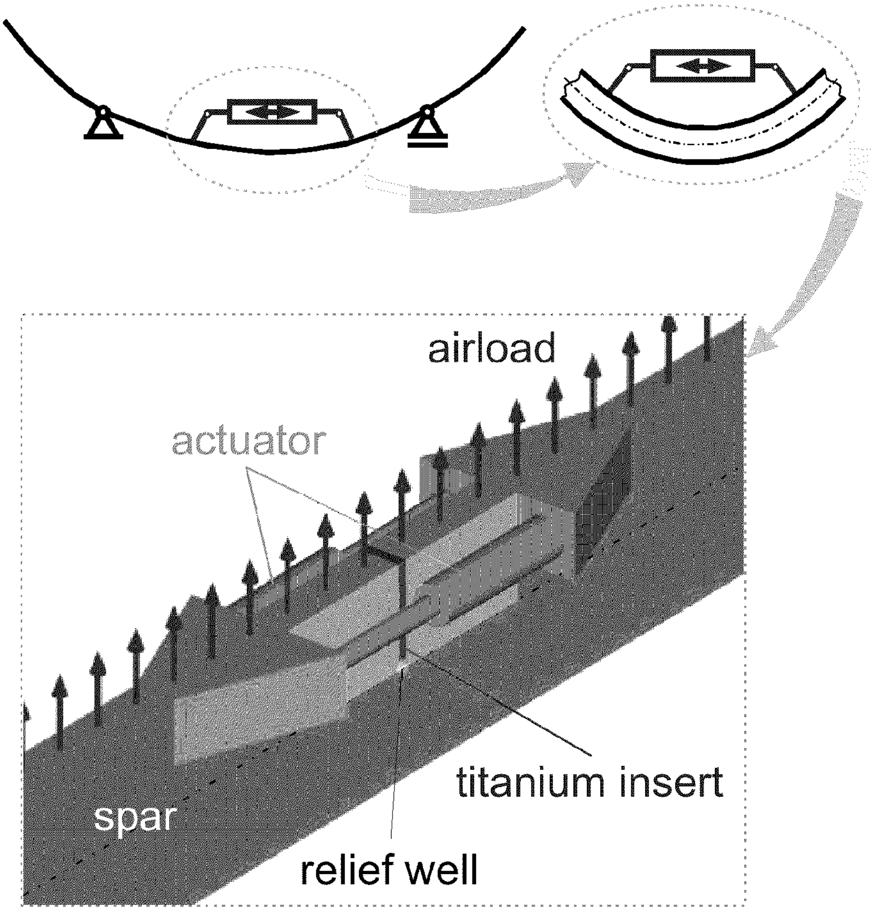

Figure 4: Integration of the actuator into the spar

The discrete actuation needs a special load spread and distribution into the structure. This interface has to be extremely stiff, otherwise the stroke of the actuator is lost due to the elasticity. There is a big variety of discrete actuators, for example piezo stacks, shape memory alloys or even hydraulic systems. For the best efficiency discrete actuators have to be integrated into the spar of the flap, because of the highest stiffness concentration. The other structural elements like ribs, stringers, and the skin remain as passive elements.

A concept for the integration of an actuator is shown in figure 4. The spar has an extremely narrow gap on the upper side (pressure side), reaching down to the relief well at or above the neutral axis. The gap is reinforced with a titanium insert for a smoother load distribution into the spar. When airload is applied, both sides of the gap are pressed together. In this case the spar acts like one without gap.

The remaining cross section of the spar must be able to withstand all occurring negative loads, e.g. landing shocks or gust loads. A stopper on the upper side of the spar guarantees, that there is no unacceptable large deformation in these cases. Due to the low negative loads, compared with the positive design loads, the stopper is only a safety device. Under normal circumstances it is not going to be used.

With the integration matrix method is it possible to calculate the deformation of the flap under the load of active forces and moments. Preliminary estimations with this method have shown, that the weight of a piezoceramic stack actuator is approximately 55 kg per flap, compared to 140 kg of the saved flaptrack.

All the above mentioned calculations were performed with a beam model and the integration matrix method. As a result, the required stiffness distributions are known. For the transfer into the real flap structure a parametric finite element model with spars, ribs, stringers, and tailored skin has to be designed (**Fig. 5**). The dimensions of the structural elements have to be varied, in order to find the solution with the lowest weight. A substitute-stiffness can be used to model the actuator. With the FE-model it is also possible to find the best fiber angle for the bending torsion coupling, in order to prevent gaps at the inner and outer side of the flap.

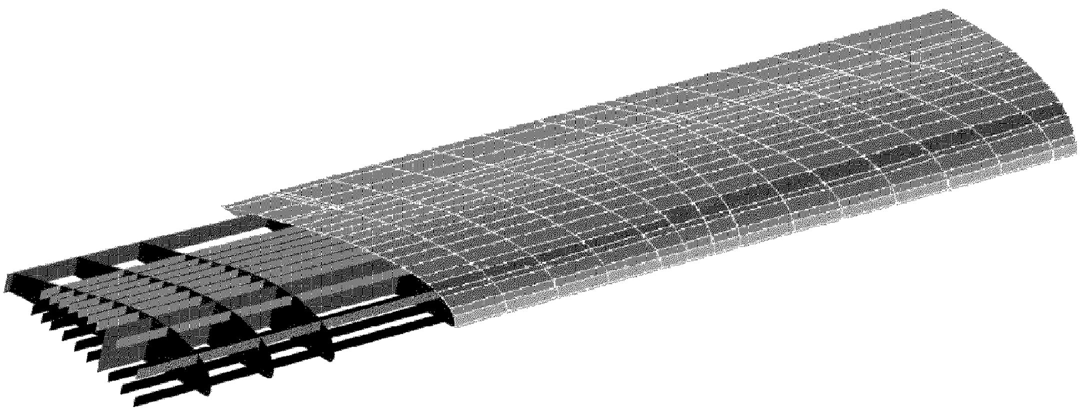

Figure 5: Finite element model of the fowler flap

When the global design of the flap is finished details have to be examined. One of the most difficult problems is the above mentioned interface between spar and discrete actuator. The spar has to be very stiff in order to provide an efficient integration, on the other hand the spar has to have a certain elasticity to be able to be deformed by the actuator [8].

Another difficult detail is the connection of the tracks and the flap itself. All forces between wing and flap are carried by the tracks. These forces are very high and have to be spread and distributed into the flap, without causing any damage.

If a piezoceramic stack actuator or a hydraulic system is used to deform the flap in the desired static way, it is possible and useful to check the dynamic properties of the flap. Although it was not a primary objective of the re-design, a vibration control will be necessary in future aircraft. At the moment there are no critical vibration problems, but with increasing size and elasticity of upcoming flaps (A3XX) this problem will become urgent in the near future. Even the influence of an actuator on the dynamic behavior of the flap can be determined. With a modal analysis is it possible to calculate the eigenvalues of the flap, using the existing finite element model. This eigenvalues are the basics for a following *Harmonic Response Analysis*. The result of this calculation is the reaction of the flap structure to the actuators stimulation.

PROBLEMS TO BE SOLVED

There are several problems that have to be solved during the redesign of the flap. The following list shows the most important ones, but does not claim to be complete.

- The optimization of the track positions and the stiffness distribution depends on a big variety of independent variables. Therefore, it is very difficult to find an absolute optimum.
- The transformation of the stiffness distribution from the beam model to the real flap offers a wide choice of structural opportunities. The solution with the minimum structural weight has to be found.
- There must be an input value of the gapsize, in order to know how the flap has to be deformed by the actuator. Two ways are possible to get this value, either with a sensor and a real time controller, or with previously measured values, depending on the angle of attack, the speed and the actual weight of the aircraft. If possible, the second way is to be favored, due to lower costs and fault liability.
- The interface spar/actuator must have an extremely high stiffness, in order to provide a good actuator performance.
- The *fail safe* concept has to be guaranteed, even if the actuator fails. Otherwise it is not possible to get the FAR- or JAR - approval for the aircraft.
- If piezoceramic stacks or shape memory alloys are used for actuation, the power supply can become problematic, due to the special energy demand of these actuators. The usage of a hydraulic actuator is no problem, due to the available hydraulic system in transport aircraft.
- The accessibility and maintainability of the active components must be possible, otherwise these elements have to be maintenance-free. The service life of the actuator or at least the TBO (time between overhaul) has to be as long as the normal maintenance interval of the flap mechanism.
- The biggest problem of all is the price of the active fowler flap. All efforts were made to increase the efficiency of the aircraft. If the achieved profit of this means is lower than their costs (initial and maintenance costs), it is not reasonable to change the flap design.

CONCLUSIONS

The presented paper describes an approach to save one flaptrack of a fowler flap, at the example of the Airbus A340. This requires a totally new design of the flap, in order to fulfill the aerodynamic demands. In the course of this redesign, a configuration can be found that improves high lift behavior as well as cruise flight efficiency. These improvements are the result of a smart combination of passive and active means. The passive design must be very accurate, in order to guarantee that the active parts of the flap are only necessary for finetuning. Therefore, a combination of optimal track positioning, reasonable stiffness distribution (including aeroelastic tailoring), pre-deformation of the flap, and integration of an actuator is necessary. First results show that the desired objectives are achievable.

ACKNOWLEDGEMENTS

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