Defense Technical Information Center
Compilation Part Notice

ADP010485

TITLE: Active Aeroelastic Aircraft and Its Impact
on Structure and Flight Control Systems Design

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: Structural Aspects of Flexible Aircraft
Control [les Aspects structuraux du controle
actif et flexible des aeronefs]

To order the complete compilation report, use: ADA388195

The component part is provided here to allow users access to individually authored sections
of proceedings, annals, symposia, ect. However, the component should be considered within
the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP010474 thru ADP010498

ACTIVE AEROELASTIC AIRCRAFT AND ITS IMPACT ON STRUCTURE AND FLIGHT CONTROL SYSTEMS DESIGN

Johannes Schweiger, Johann Krammer
DaimlerChrysler Aerospace AG
Military Aircraft
P. O. Box 801160
D-81663 Muenchen
Germany

Abstract

Active aeroelastic concepts have been proposed for several years now. Their common incentive are improvements of aircraft performance and stability by the intentional use of aeroelastic effects. This means that the basic flexibility characteristics of a new aircraft project must be included in the early conceptual design process, and the structural and flight control system design must be coupled very closely.

The knowledge about the magnitude of aeroelastic impacts on aerodynamic forces and aircraft stability is still very limited within the community of people involved in aeronautical engineering - even among the specialists in aeroelasticity. For a successful application of active aeroelastic concepts, their proper identification is therefore the first step. It will be shown for some selected examples, which static aeroelastic effects are usually very important for conventional designs, and how they can be made even more effective in a positive sense for future designs.

The accuracy and proper use of aeroelastic prediction methods and analysis models is addressed briefly in the context of interactions with other disciplines, and ideas are developed for the multi-disciplinary design process of active aeroelastic aircraft concepts.

Whereas static aeroelastic effects usually only become important with increasing airspeed, a concept will be demonstrated for aeroelastic improvements, which also works at low speeds.

1. Introduction

Traditionally, aircraft structure and flight control design could be handled as quite independent processes. The flight control concept was defined as a part of the conceptual design process. After this, the structural design concept was defined, taking into account that the structure had to be strong enough to bear the loads for all desired maneuvers, including the forces from the predefined control surfaces. The detailed dimensions of the individual structural components could then be determined by a refined assessment and distribution of aerodynamic and inertia loads. For each of the following design loops, these loads were considered invariable from changes of the local mass distributions, from resulting changes of the control forces, or from aeroelastic effects on the aerodynamic loads. These changes could only be analyzed after each major design loop, and then be used as an update for the next loop.

This hierarchical approach allowed no feed-back from the structural design to the flight control system design. In the past, flexibility or structural dynamic effects could only be identified and quantified very late in the design process. This resulted in additional weight, degraded performance, or costly redesigns. On the flight control side, adjustments to optimize the handling qualities could be made quite easily during the flight test program, as long as the flight control system was manually actuated. This was also possible, if servo actuators were used. Even an analog electrical flight control system with feed-back loops allowed quick fixes or adjustments by trial and error methods.

For a modern airplane the development of the digital flight control system is a time consuming and costly process. Therefore, it is today much more important, to know the aeroelastic characteristics of the airplane as good and as early as possible during the design process.

This fact becomes even more important, when active aeroelastic concepts are considered for a design. They will either have their own control system, which may create strong interactions with the aircraft's main flight control system, or they are directly controlled by this one. In this case, it means direct impacts on the flight control system's authority and stability.

2. Historic developments

Although aeroelasticity was still completely unknown to the pioneers of aviation, the success of the first powered flight may be contributed to a great extend to a sophisticated active aeroelastic concept for directional control. In his book "How we invented the airplane"[1], Orville Wright describes this system of cables, connecting the sliding cradle, which could be moved by the pilot, to the wing tips, which were twisted by the pilot' motion in opposite directions. This provided roll control without ailerons.

On the other hand, the Wright brothers' main competitor, Samuel P. Langley, was very likely less fortunate with his Aerodrome designs because of insufficient aeroelastic stability[2].

An other example demonstrates how strongly interdisciplinary the design of airplanes already was in those early years. During the First World War, designers and government authorities began to fear the loss of structural integrity from battle damage and looked for redundancy of major load-carrying parts. In the case of the monoplane Fokker D.VIII, shown in Figure 1, a superior design with cantilevered wings, where the box structure provided excellent redundancy, the rigid certification rules caused a series of fatal accidents,

which were caused by aeroelastic divergence. As Anthony Fokker describes in his book[3], sufficient strength of the design had already been demonstrated by proof load and flight tests, when regulations called for a reinforced rear spar with proportional strength capacity to the front spar. This redistribution of stiffness caused torsional divergence under flight loads.
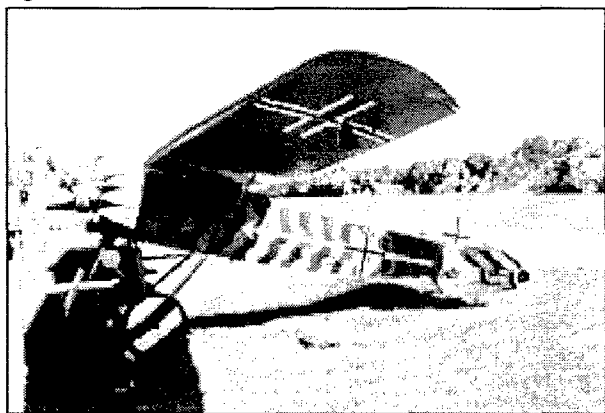

Figure 1: Fokker monoplane D-8

In the following years, designers began to fear the flexibility of the structure, as quoted from a review paper on Aeroelastic Tailoring by T. A. Weisshaar[4] *"As a result, aeroelasticity helped the phrase "stiffness penalty" to enter into the design engineer's language. Aeroelasticity became, in a manner of speaking, a four-letter-word. ...it deserves substantial credit for the widespread belief that the only good structure is a rigid structure."*

Only recently the authors could listen to this demand again, when a colleague from flight control systems design asked to build future airplanes as rigid as possible.

Today, the high performance of fighter aircraft, and the increasing size of transport aircraft, together with modern light weight structures, have enlarged the flexibility effects on the aerodynamic characteristics of airplanes. Modern airplanes are also operating more often near and closer to the high speed edge of the flight envelope. In the past, it was for example sufficient to ensure the avoidance of aileron reversal at limit speed, a speed where the aircraft would usually not operate.

In the past, the structural dynamic characteristics of an airplane had only rarely to do with the flight control system. Flutter as the classical aeroelastic instability could be treated independently from the flight control system by proper adjustments to the stiffness and mass distributions. The frequency band of the aircraft's rigid body Eigenmodes and the dynamic characteristics of the control surface actuators were usually well below those of the flexible aircraft. Today's actuators however as well as the speed of the flight control computers are causing overlaps which require careful aeroservoelastic analysis. Stability deficiencies are usually treated by implementing notch filters for the structural dynamic Eigenfrequencies into the flight control laws. For a fighter airplane which is usually flying in many different configurations and at different flight conditions, a multitude of these filters may be required to provide sufficient stability. This usually results in a considerable degradation of the aircraft's agility.

This implies that a different approach will be required in the future for the treatment of flight control system and structure

in the design process, with or without active aeroelastic concepts.

3. Active aeroelastic concepts

3.1. Definitions for active aeroelastic concepts

In a more traditional sense, active aeroelastic concepts can be defined as active control concepts for the cure of static or dynamic aeroelastic deficiencies with respect to stability, maneuverability, loads, or aerodynamic performance. In this case, the aeroelastic impacts are considered to be bad in general.

Examples are gust load alleviation or active flutter suppression concepts, where control surfaces are actively deflected to counteract loads or create unsteady aerodynamic damping forces. One reason why these systems did not become common practice, is the insufficient static aeroelastic effectiveness of typical control surfaces like ailerons.

Since several years, the expression "active aeroelastic" is more used for concepts, where aeroelastic effects are exploited in a beneficial way to improve aircraft performance, handling, or directional stability compared to a rigid aircraft. Using this definition, only static aeroelastic concepts are addressed.

Possible benefits from aeroelasticity were already addressed in the seventies and eighties, when advanced composite materials together with formal structural optimization methods offered the possibility of Aeroelastic Tailoring an aircraft structure[5]. One of the first demonstrations was the Active Flexible Wing wind tunnel test program[6]. On this model, Figure 2, two leading and two trailing edge surfaces are adaptively deflected at different aerodynamic conditions to achieve optimum roll control power. This multiple surface control concept allows to use the trailing edge surfaces beyond their reversal speed.
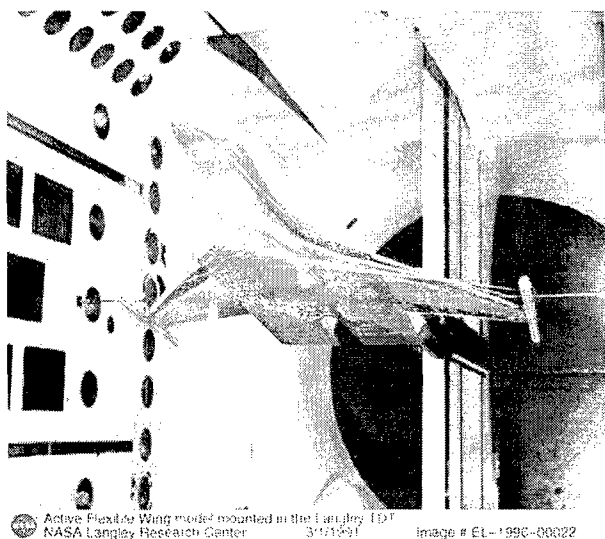

Figure 2: Active Flexible Wing wind tunnel model

To demonstrate this concept in flight, an F-18 is currently modified with a more flexible wing, other control surfaces, and the appropriate flight control laws[7] .A more flexible wing means in this case, that an original F-18 wing torque box will be used. This structure had to be reinforced after initial tests because it did not provide the desired roll control power.

The expression "Active Flexible Wing" may have mislead to the believe that an airframe structure must now be made as flexible as possible to improve an airplane's performance.

This is as wrong as the above quoted "as rigid as possible", because excessive weight penalties would be created in both cases. The objective must be a minimum weight design, where the external geometry, the arrangement and shape of control surfaces, are optimized together with the flight control law to achieve aeroelastic tuning or amplification of aerodynamic forces at all flight conditions.

Additional interest in active aeroelastic concepts arose in recent years with the development of active materials, where the stiffness can actively be adjusted. Active structures concepts, where the stiffness of individual components is actively modified, also belong to this category.

The overview paper from McGowan et al.[8] gives an excellent overview on recent activities for static and dynamic aeroelastic applications.

3.2. Classification of active aeroelastic concepts

3.2.1. Classification by aeroelastic phenomena

If the definition of active aeroelastic concepts is expanded to all active concepts, where structural dynamics or aeroelasticity are involved, the elastic mode control system ILAF (Identically Located Acceleration and Force)[9] of the XB-70 must be considered as one of the first applications. A similar system is installed today on the B-1B to counter turbulence.

In the seventies, active flutter suppression systems by means of activated control surfaces were developed and flight tested[10]. Besides the criticality aspect of a potential system failure, an other reason, why they are not yet in use, may be their limited static aeroelastic effectiveness, as already mentioned above.

In recent years, active concepts for the alleviation of dynamic loads from buffeting conditions of vertical tails were designed and tested in wind tunnels and on full scale ground tests with simulated loads[11,12].

The first demonstration of active materials concepts for the reduction of dynamic loads in a flight test was a smaller structural component. Piezo-active elements were used to reduce the vibration loads on a skin panel of the B-1B rear fuselage section[13].

The group of concepts, where aeroelastic phenomena can be used in a beneficial way, can be subdivided for the following applications.

Improvements of directional control forces by using classical aerodynamic control surfaces as tabs to initiate the main control force by an aeroelastic deformation of the fixed surface. Theoretically, the same effect could be achieved by an active deformation of the fixed surface directly. Several studies[14,15,16,17,18] demonstrate the principle of these concepts and explain the required design approach. Mainly roll control is addressed by these concepts, because the outboard ailerons on wings usually show the highest aeroelastic sensitivity.

A second application of static aeroelastic concepts is the reduction of gust or maneuver loads. Active load alleviation concepts in the past suffered from a lack of aeroelastic effectiveness of the control surfaces – usually the outboard ailerons.

Mainly for transport aircraft wings, active aeroelastic concepts offer an attractive opportunity to adjust the shape of the flexible wing for minimum drag under varying flight and internal loading conditions.

So far, mainly wings have been addressed by active aeroelastic concepts. But horizontal and vertical tails could be at least as attractive. Whereas wings have to meet a multitude of design objectives and requirements, which somehow limit the design space for active aeroelastic tailoring, the only purpose of empannage surfaces is the provision of directional stability and directional control about the pitch and yaw axis. This means, that they offer a larger design space. One such concept for a vertical tail is described below.

3.2.2. Classification by active devices

There are two major groups of active devices: aerodynamic control surfaces and structural devices. The first one creates external aerodynamic forces to stimulate deformations of the flexible fixed surface, while the other one is based on interactions between the active elements and the passive structure by internal forces.

The effectiveness of aerodynamic actuators relies upon the aerodynamic flow conditions. Their power increases linear with the dynamic pressure at smooth flow conditions. For turbulent flow, for example at high angles of attack, or for large deflections, they can completely lose their effectiveness. This makes them very efficient for applications at high speeds, where only small deflections are required. But this also requires, that their natural static aeroelastic effectiveness is high. Natural means that it already comes from the wing or stabilizer planform geometry and location of the control surfaces, with no additional investment of stiffness and weight.

Aerodynamic control surfaces are limited for dynamic applications by the frequency range of their hydraulic actuator. The active control system has to be integrated into the main flight control system, and depending on the required control surface authority, they will limit the basic aircraft performance.

The effectiveness of the achievable actuation from active structures and materials concepts is independent from the external flow conditions. The achievable stimulation of aeroelastic servo-effects however also here depends on the basic geometry and structural arrangement.

Their effectiveness relies upon the optimum placement within the passive structure to achieve the best possible deformation of the flexible structure. Active materials can be embedded within the passive structure or attached to, distributed over larger areas, or concentrated active elements are acting between a few selected points for high authority.

It is sometimes said that these concepts could completely replace conventional control surfaces. But this looks very unrealistic at the moment. The major difficulties for a successful application are here the limited deformation capacity of active materials, as well as their strain allowables, which are usually below those of the passive structure. However, this can be resolved by a proper design of the interface between passive and active structure. But the essential difficulties are the stiffness and strain limitations of the passive structure itself. It can not be expected that the material of the passive structure just needs to be replaced by more flexible materials without an excessive weight penalty. It

is also not correct to believe that an active aeroelastic concept will become more effective, if the flexibility of the structure is increased. The aeroelastic effectiveness depends on proper aeroelastic design, which needs a certain rigidity of the structure to produce the desired loads. A very flexible structure would also not be desirable from the standpoints of aerodynamic shape, stability of the flight control system, and transmission of static loads.

Because large control surface deflections are required at low speeds, where aeroelastic effects on a fixed surface are small, it is more realistic to use conventional control surfaces for this part of the flight envelope, and make use of active aeroelastic deformations only at higher speeds. This would still save weight on the control surfaces and their actuation system due to the reduced loads and actuation power requirements.

4. Optimization methods in aircraft design

Any improvement of a technical system is often referred to as an optimization. In structural design, this expression is today mainly used for formal analytical and numerical methods. Some years after the introduction of finite element methods (FEM) for the analysis of aircraft structures, the first attempts were made to use these tools in an automated design process. Although the structural weight is usually used as the objective function for the optimization, the major advantage of these tools is not the weight saving, but the fulfillment of aeroelastic constraints. Other than static strength requirements, which can be met by adjusting the individual finite elements' dimensions, the sensitivities for the elements with respect to aeroelastic constraints can not be expressed so easily.

In the world of aerodynamics, the design of the required twist and camber distribution for a desired lift at minimum drag is also an optimization task. Assuming that minimum drag is achieved by an elliptical lift distribution along the wing span, this task can be solved by a closed formal solution and potential flow theory. More sophisticated numerical methods are required for the 2D-airfoil design or for Euler and Navier-Stokes CFD methods, which are now maturing for practical use in aircraft design.

For the conceptual aircraft design, formal optimization methods are used since many years. Here, quantities like direct operating costs (DOC) can be expressed by rather simple equations, and the structural weight can be derived from empirical data. Formal methods like optimum control theory are also available for the design of the flight control system.

So one might think that these individual optimization tasks could easily be coupled for one global aircraft optimization process. The reasons why this task is not so simple are the different nature of the individual disciplines' design variables, and their cross sensitivities with other disciplines. The expression Multi-Disciplinary Optimization (MDO) summarizes all activities in this area, which have been intensified in recent years. It must be admitted that today most existing tools and methods in this area are still single discipline optimization tasks with multi-disciplinary constraints.

In order to design and analyze active aeroelastic aircraft concepts, especially when they are based on active materials or other active structural members, new quantities are required to describe their interaction with the structure, the flight control system, and the resulting aeroelastic effects.

Besides formal methods, an efficient MDO approach also requires experienced engineers with a broad knowledge in all involves disciplines and their interactions. It is also essential, that the proper levels of single-discipline analysis models and methods are used for the integrated design process.

5. Approach for the aeroelastic analysis of an active structure

For the static aeroelastic analysis of the achievable rolling moment, induced by active structural elements, the optimization program LAGRANGE[19] was modified. For the static aeroelastic analysis of a conventional passive structure, the analysis process is initialized by defining the aerodynamic deflections of control surfaces. The resulting "rigid" aerodynamic load is then used as a starting point to obtain the aeroelastically balanced equilibrium condition, as depicted in Figure 3.
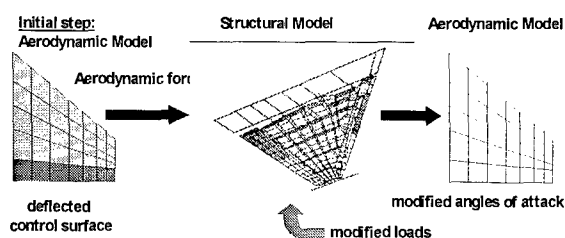

Figure 3: Process for static the aeroelastic analysis with control surfaces

For an active structure, the chosen new approach first simulates the deformation of the structure under the loads of the activated elements. This static solution delivers the initial angle-of-attack distribution for the aeroelastic analysis, as shown in Figure 4.
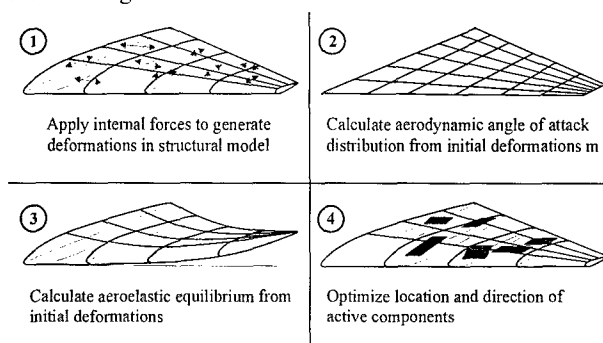

Figure 4: Static aeroelastic analysis steps for an active structure

To verify the approach, three different cases were analyzed, using the wing model from the example below: one for a conventional control surface deflection by specifying its initial aerodynamic deflection, one with the equivalent deflection from static loads applied to the element that represents the actuator, and one, where in-plane loads are applied to the skins of the control surface. The results are shown in Figure 5.
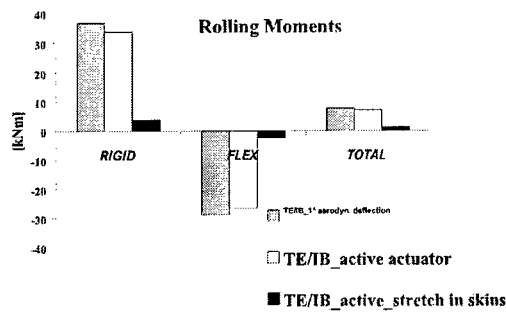
Figure 5: Results for test cases

6. Examples for active aeroelastic concepts

6.1. Active aeroelastic wing

To demonstrate the principle of active aeroelastic concepts for improved roll performance, a low aspect ratio fighter aircraft wing was chosen., because here one would not expect considerable aeroelastic improvements. The Finite Element model for this generic wing is shown in Figure 6.

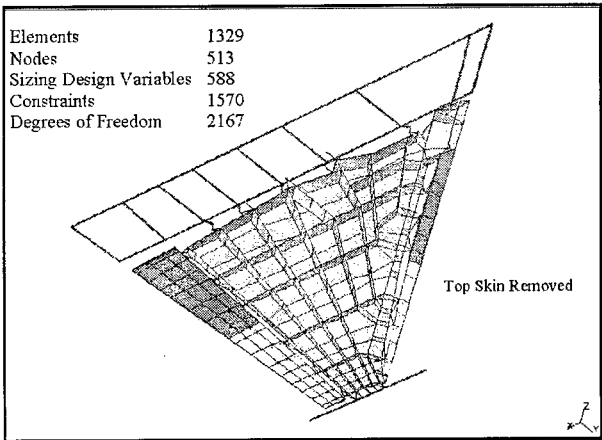| Elements | 1329 |
Nodes	513
Sizing Design Variables	588
Constraints	1570
Degrees of Freedom	2167

Top Skin Removed

Figure 6: Finite Element model for low aspect ratio fighter wing

The original model, which had only two trailing edge flaperons for roll control, was modified by two addition leading edge surfaces for roll control. The had to be rather small to avoid modifications of the torque box structure. Figure 7 shows their representation in the aerodynamic analysis model. The basic design conditions for the optimization are summarized in table 1.
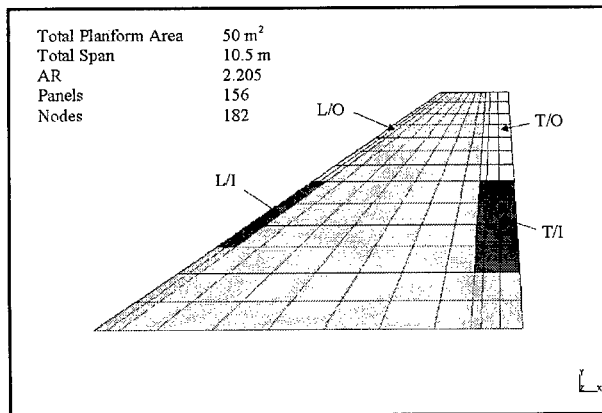

Total Planform Area	50 m²
Total Span	10.5 m
AR	2.205
Panels	156
Nodes	182

Figure 7: Aerodynamic model of the wing

Static load cases	+ 9g , - 4g
Roll rate at Ma 1.2, S/L	120 °/s
Max. hinge moment per surface	15 kNm
Max. control surface deflection	15 °

Table 1: Basic wing design conditions

Figure 8 depicts the achievable rolling moment with increasing airspeed for rigid conditions. These two graphs clarify, why usually only trailing edge surfaces are considered for roll control. Besides their different size, main reasons for better aerodynamic performance are the different sweep angles, and mainly the camber effect, which supports the trailing edge surfaces and counteracts at trailing edge deflections.
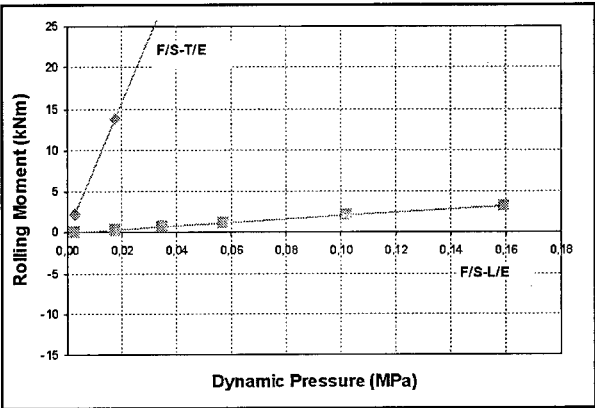

Figure 8: Achievable rolling moment for a 1° deflection of leading and trailing edge surfaces without structural flexibility

But things look quite different, as soon as the aeroelastic effects on the flexible structure are taken into account. For the initial structure, which had already been optimized for increased rolling moment effectiveness of the trailing edge surfaces, the achievable rolling moments are compared in Figure 9.
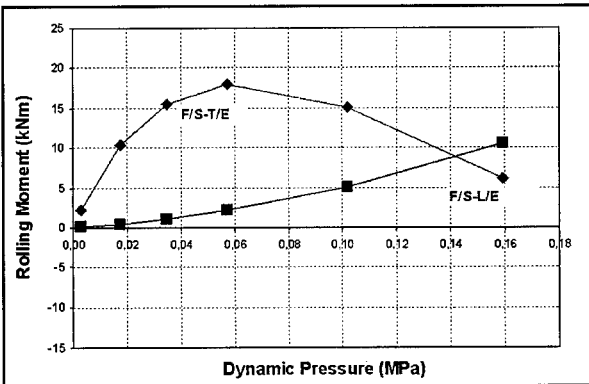

Figure 9: Rolling moments for leading and trailing edge surfaces with flexibilities of the initial design

Traditionally, if only the trailing edge surfaces are used for roll control, the achievable roll rates for a design with fixed planform and control surface geometry can only be improved by additional structural weight. For this example, the structural optimization of the wing box skins with different constraints for the rolling moment effectiveness results in the graph of Figure 10 for skin weight and effectiveness. If the leading edge surfaces are used in addition, the results in table 2 can be achieved for the basic static design. If buckling

stability is not considered for the wing skin design, which could be possible by additional spars, the rolling moments vs. dynamic pressure for the individual control surfaces in Figure 11 are obtained. In this case, the leading edge surfaces get more effective, and the trailing edge surface could be used beyond the reversal speed. More details about this study are reported in refs.[16,17].
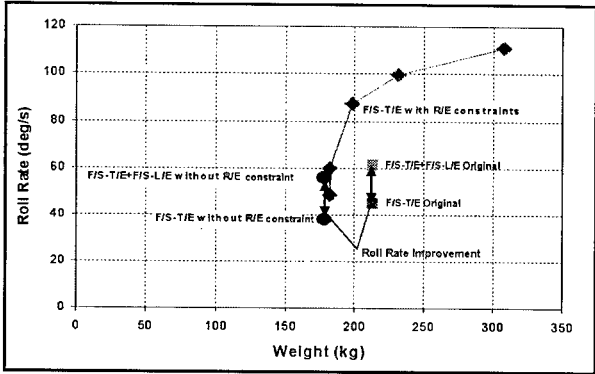

Figure 10: Optimization results with different rolling moment effectiveness constraints

	Conventionally optimized design	Static design with additional roll control from L/E surfaces		
		Without L/E	With L/E, basic configuration	With L/E, 50 % larger. differential deflections
Skin weight per side [kg]	307	178	178	178
Total rolling moment for 1 °				
T/E – I/B	32.0	9.00	9.00	9.00
T/E – O/B		2.94	2.94	2.94
L/E – I/B			2.39	2.59
L/E – O/B			3.01	4.52
Total hinge moment for 1 °				
T/E – I/B	3.07	2.86	2.86	2.86
T/E – O/B	1.79	1.53	1.53	1.53
L/E – I/B			0.34	0.51
L/E – O/B			0.20	0.30
Required hinge moment for 120 ° /s and flap deflection [kNm]				
T/E – I/B	16.1, 5°	47.0, 16.5°	32.1, 11.4°	14.3, 5.0°
T/E – O/B	9.4, 5°	27.7, 16.5°	18.7, 11.4°	15.3, 5.0°
L/E – I/B			3.8, 11.4°	7.7, 15.0°
L/E – O/B			2.2, 11.4°	4.5, 15.0°

Table 2: Optimization results for the wing
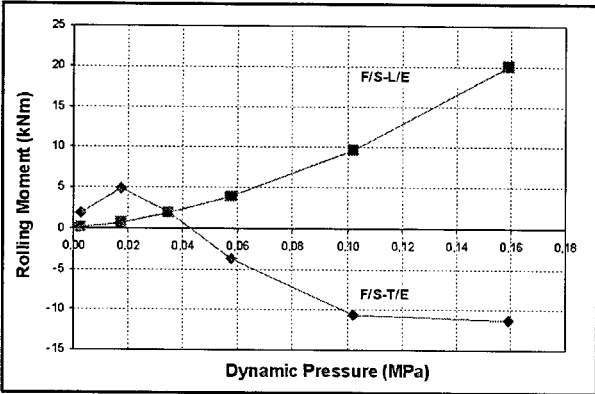

Figure 11: Rolling moments for the static design without buckling stability

6.2. Active aeroelastic vertical tail

The structural design of the vertical tail for a fighter aircraft usually requires additional stiffness for the static aeroelastic effectiveness of the lateral stability and for the rudder yawing moment. A typical effectiveness-vs.-weight trend is depicted in Figure 12. To improve this situation, the concept of a Diverging Tail was developed by Sensburg et al.[20].In a first step, the effectiveness is increased by means of aeroelastically tailored skins.
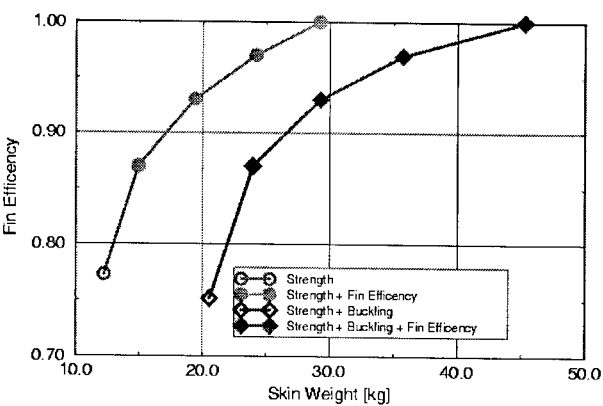

Figure 12: Static aeroelastic effectiveness vs. structural weight for a typical vertical tail

Although this means a weight increase for the cover skins, the total structural weight can be decreased by reducing the size of the tail proportional to the increase in effectiveness. Additional increases are then obtained by relaxing the stiffness of the forward root attachment and modifying the rear attachment in such a way that the aerodynamic surface can be deformed in a more favorable way.

For further improvements, the concept of an Active Vertical Tail was developed. The principle is depicted in Figure 13. It is an all-movable tail, where the attachment is positioned in such a way, that the aeroelastic effectiveness is above 1.0 for all aerodynamic flow conditions. The amount of effectiveness can be adjusted by a variable torsional stiffness element. This can for example be achieved by a mechanical, hydraulic, electric, or active materials system. The actuation of the tail for yaw control can be integrated into the same system, or it can be designed as a separate system. A separate actuation system by a conventional actuator with constant stiffness would be less complex for the flight control system.
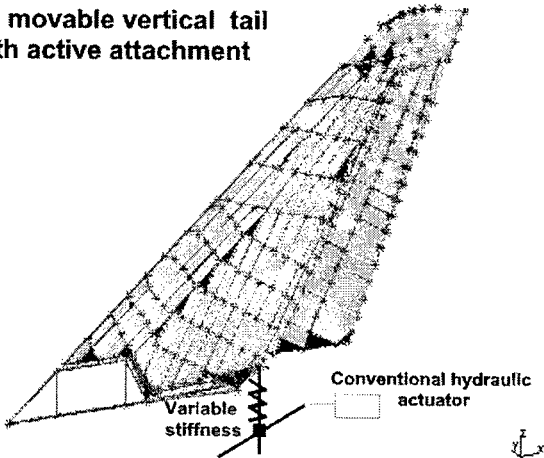

Figure 13: Concept of an all-movable Active Vertical Tail

This vertical tail needs no additional weight for aeroelastic effectiveness. Its size can be reduced to the value, where sufficient directional stability and yaw control are provided by the proper amount of effectiveness from the variable attachment stiffness. The lower boundaries for the stiffness are defined by sufficient flutter stability. This means, that flutter stability and aeroelastic effectiveness have the same stiffness demands: low at low speeds, and high at high speeds.

This concept reverses the traditional design approach for improved aeroelastic effectiveness, where an increase is

achieved by additional stiffness. Whereas the minimum size of the passive design for the diverging tail is limited by stability and control requirements at low speeds, where no aeroelastic effectiveness improvements are possible, the Active Vertical Tail also provides increased effectiveness at low speeds.

A different concept for a variable stiffness actuation system is already used for the new F/A-18E/F[21]. Here the hydraulic pressure switches from 207 bar to 345 bar (3000 to 5000 PSI) at high dynamic pressures to compensate aeroelastic losses.

7. Impacts from active aeroelastic concepts on the FCS design

The design of the flight control system should not become more complex because of an active aeroelastic concept. But the impacts from this active concept on the aircraft's parameters, which are implemented in the flight control laws, must be known and respected.

The performance of the flight control system should not be degraded in the presence of an active aeroelastic system. If designed properly, there should even be improvements, like reduced power and stiffness demands for the flight control actuation system.

As an example, the simplified schedule in the flight control laws for the leading and trailing edge surfaces for roll control of the wing above could look like in Figure 14.
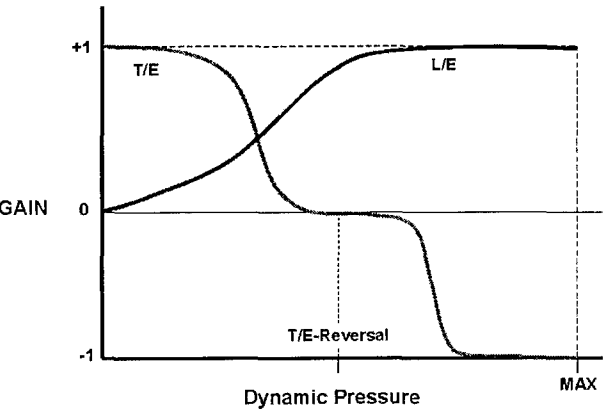
Figure 14: Leading and trailing edge control surface authority for roll control

The variable stiffness for the attachment of the vertical tail might look like in Figure 15. Here, the optimum stiffness for aeroelastic effectiveness must be tuned together with the flight control laws for handling and stability requirements.

8. Impacts from active aeroelastic concepts on the structural design

In order to incorporate active aeroelastic concepts into the structural design, it is no longer sufficient to specify aeroelastic constraints like for flutter or control surface effectiveness, and apply it to the structural optimization process for a predefined structural concept.

The design space for aeroelastic effects must be as wide as possible in the beginning. That means, the sensitivities of basic geometry parameters for wings and control surfaces, the positions of control surfaces, and their functions must be considered as design variables in the beginning.

Figure 15: Attachment stiffness requirements for Active Vertical Tail

The design space for aeroelastic effects must be as wide as possible in the beginning. That means, the sensitivities of basic geometry parameters for wings and control surfaces, the positions of control surfaces, and their functions must be considered as design variables in the beginning.
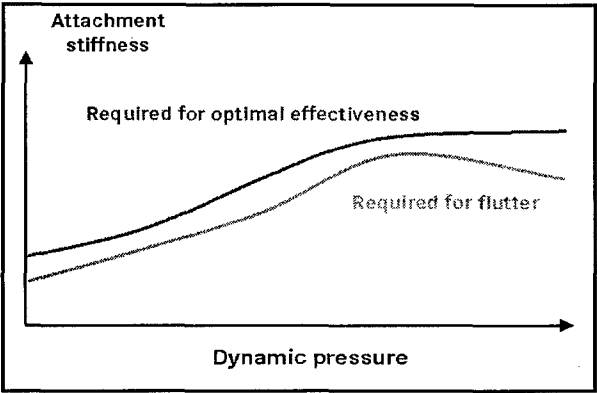
The analytical description of active aeroelastic concepts must directly be included in the structural analysis model because of the impacts from the passive structure's design constraints on the effectiveness of active aeroelastic systems. In order to make them efficient, it is required to understand, design and simulate the interfaces between components and the passive, load-carrying structure.

9. Needs for the integrated design of airplanes with active aeroelastic concepts

It is obvious that integrated design and multi-disciplinary optimization processes are an absolute must for active aeroelastic concepts.

MDO does not mean to combine single discipline analysis tools by formal computing processes. It means first a good understanding of what is going on. This is already essential for a conventional design. Only after this understanding the creative design of an active concept can start.

It is then very important to choose the proper analysis methods for the individual disciplines. Usually, not the highest level of accuracy is suitable for the simulation of important effects for other disciplines. This also refers to refinement of the analysis models, where local details are not interesting for interactions. It is more important to keep the models a versatile as possible for changes of the design concepts to allow the simulation as many variants as possible. This also means an efficient process for the generation of models, including the knowledge of the user for this process. Fully automated model generators can create terrible results, if the user can not interpret or understand the modeling process.

Also the quality and completeness of analysis models is essential, as far as impacts on neighbor disciplines are concerned. Especially for formal optimization processes, model errors will create foolish results. To achieve good results, a careful selection and combination of the design variables and the completeness of the design requirements are important.

10. Conclusions

The qualities and quantities of impacts from aeroelasticity on structural loads, aerodynamic performance, maneuverability,

stability and agility of the flight control system of an airplane became more and more important in recent years. This fact is now more and more often also recognized outside the aeroelastic community.

Especially the complexity of a modern digital flight control system requires a careful identification of aeroelastic impacts to avoid degradations or costly redesigns. If an efficient MDO process can be set up early enough for a new design, aeroelastic impacts can be minimized or can even be used in a positive sense.

While this is slowly being accepted for a conventional design, concerns are already expressed, that active aeroelastic concepts may not be desirable because of possible negative interferences with the flight control system, which is already complex enough.

The development of active aeroelastic concepts should therefore not merely be seen as a task in aeroelasticity. It must be a creative part of the overall flight control system design, together with the aerodynamic and structural design. This process must include experts from all involved disciplines (flight control laws, actuation systems, including those for active structures, aerodynamics, structure, and aeroelasticity) with a good understanding of the other disciplines.

If this is possible, great achievements from active aeroelastic concepts can be expected for future designs of airplanes and all kinds of flying vehicles.

References

[1] Wright, O.: How we Invented the Airplane. Dover Publications, Mineola, NY, 1988

[2] Flomenhoft, H. I.: The Revolution in Structural Dynamics. Dynaflow Press, Palm Beach Gardens, FL, U.S.A..1997

[3] Fokker, A. H. G.; Gould, B.: Flying Dutchman. The Life of Anthony Fokker. Henry Holt and Company, New York, U.S:A., year unknown

[4] Weisshaar, T. A.: Aeroelastic Tailoring – Creative Use of Unusual Materials. AIAA-87-0976-CP

[5] Shirk, M. H.; Hertz, T. J.; Weisshaar, T. A.: A Survey of Aeroelastic Tailoring – Theory, Practice, Promise. AIAA-84-0982-CP

[6] Journal of Aircraft, Vol. 32, No.1, Special Section: Active Flexible Wing, 1995

[7] Pendleton, E.; Griffin, K.E.; Kehoe, M.W.; Perry, B.: A Flight Research Program for Active Aeroelastic Wing Technology. Conference Proceedings AIAA-96-1574-CP

[8] McGowan, A.-M. et al.: Aeroservoelastic and structural dynamic research on smart structures conducted at NASA Langley Research Center. SPIE Vol. 3326, 1998.

[9] Pace, S.: Valkyrie- North American XB-70A. Aero Series Vol. 30; Tab Books, Blue Ridge Summit, PA, U.S.A..1984

[10] Noll, T.; Hönlinger, H.; Sensburg, O.; Schmidt, K.: Active Flutter Suppression Design and Test, a Joint U:S.-F.R.G. Program. ICAS- CP 80-5.5. Munich, Germany, 1980.

[11] Hopkins, M.A.; Henderson, D.A.; Moses, R.W.: Active Vibration Suppression Systems Applied to Twin Tail Buffeting. SPIE's 5th Annual International Symposium „Smart Structures and Materials". San Diego, CA, 1998.

[12] Simpson, J.; Schweiger, J.: Industrial Approach to Piezo-electric Damping of Large Fighter Aircraft Components. SPIE's 5th Annual International Symposium "Smart Structures and Materials". San Diego, CA, 1998.

[13] Larson, C.R.; Falanges, E.; Dobbs, S.K.: Piezoceramic Active Vibration Suppression Control System Development for the B-1B Aircraft. SPIE's 5th Annual Interntional Symposium "Smart Structures and Materials". San Diego, CA, 1998.

[14] Crowe, C.R.; Sater, J.M.: Smart Aircraft Structures. AGARD Symposium on Future Aerospace Technology in the Services of the Alliance. CP-600, Vol. I. Paris, 1997

[15] Andersen, G.; Forster, E.; Kolonay, R.; Eastep, F.: A Study of Control Surface Blending for Active Aeroelastic Wing Technology. 37th AIAA-SDM Conference CP-96-1443

[16] Khot, N.; Eastep, F.; Kolonay, R.: A Method for Enhancement of the Rolling Maneuver of a Flexible Wing. AIAA-CP-96-1361.

[17] Schweiger, J.; Simpson, J.; Weiss, F.; Coetzee, E.; Boller, Ch.: Needs for the analysis and intedrated design optimization of active and passive structure for active aeroelastic wings. SPIE's 6th Annual International Symposium on "Smart Structures and Materials". Newport Beach, CA, 1999.

[18] Schweiger, J.; Krammer, J.; Coetzee, E.: MDO Application for Active Flexible Aircraft Design. 7th AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization. CP-4169, St. Louis, MO, 1998.

[19] Schweiger, J.; Krammer, J.; Hörnlein, H.: Development and Application of the Integrated Structural Design Tool LAGRANGE. 6th AIAA/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization. CP-4169, Seattle, WA, 1996

[20] Sensburg, O.; Schneider, G.; Tischler, V.; Venkayya, V.: A Unique Design for a Diverging Flexible Vertical Tail. Specialists' Meeting on Structural Aspects of Flexible Aircraft Control. RTA Meeting on Design Issues. Ottawa, Canada; October 1999.

[21] Balanced Upgrade. Flight International, January 20-26 1999.