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# Integration of Structural Optimization in the General Design Process for Aircraft

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**Formal mathematical optimization methods have been developed during the past 10–15 yr for the structural design of aircraft. Together with a reliable analysis program like finite element methods (FEM), they provide powerful tools for the structural design. They are efficient in at least two ways: 1) by producing designs that meet all specified requirements at minimum weight in one step and 2) relieving the engineer from a time-consuming search for modifications that give better results, they allow more creative design modifications. MBB has developed an optimization code called MBB-LAGRANGE which uses mathematical programming and gradients to fulfill different constraints simultaneously. A method for solving large linear equation systems by an iterative method is described to show the effort which went into the program, formulating the physical problem in a very efficient mathematical way. Some examples depicting the successful application of the MBB-LAGRANGE code are presented. This article closes with an outlook on how the optimization problem could be enlarged to include also the shape and size of airplanes.**

## I. Introduction

TO improve or modify a design, a process, a procedure, or any given task into a "better" direction, is referred to as "optimization." This is often done by experience, parametric investigations, iterative procedures, experimental testing and modifications, or it is based on empirical data. This approach usually leads to better results, but nobody can tell how far away the optimum still is or even where it is. A more efficient way to perform this task is provided by a special branch of applied mathematics, called optimization. This kind of optimization changes the chosen variables in a design problem in a way to achieve the best value for an objective while not violating defined constraints that represent the boundaries of the design space.

This formal optimization was introduced early in economics or chemical engineering due to the linearity of the problems, as described by Ashley[1] in an excellent overview paper on the aeronautical use of optimization. In order to use the potential of mathematical optimization, it is necessary to describe the physical nature of the problem in a way that allows the use of optimization algorithms.

In structural design, finite element methods (FEM), together with modern computers, have provided tools that analyze complex structures with high accuracy. These were main essentials to initiate development and application of optimization programs for structural design since 1970. Approximately at the same time, composite materials were introduced in aerospace design. They offer an infinite variety to combine their highly anisotropic elastic properties for any specific combination of design requirements. For a more efficient use of these materials, optimization programs are required to handle the complexity of the problem, especially if additional requirements, besides strength, are involved in the problem.[2] During the last decade, considerable effort has been spent to develop modern structural optimization procedures, using efficient mathematical optimization algorithms, as well as optimal criteria which satisfy all requirements simultaneously and find optimal values of the design variables by direct computation. The increasing emphasis of aeroelastic considerations is shown in Fig. 1, which was taken from Ref. 3.

## II. Structural Optimization in the General Data Flow

The use of structural optimization tools during the preliminary design stage of an advanced aircraft gives the following potential improvements. It satisfies the requirements of new aircrafts and minimizes the objective weight. It increases the quality of products and shortens the development phase. It also improves chances of the company in competition.

In order to do this, an appropriate mathematical programming procedure has to be embedded in the general data flow.[4]

Figure 2 shows a typical flow of geometric, aerodynamic, structural, and other data which are used during the design phase of an aircraft. The improved productivity is a result of the integrating effects of the structural optimization. Shorter time of development is realized and fewer data transfers go wrong.

At the present time, the development of new airplanes is influenced by new techniques, such as flutter suppression, CCV-configuration, gust load alleviation, etc. (Fig. 2). In

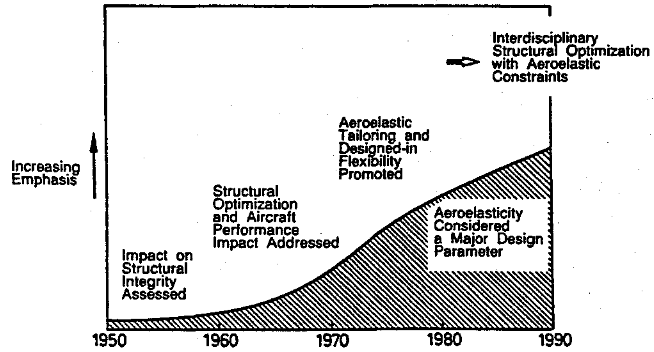


Fig. 1 Evolution of aeroelastic considerations in aircraft design.

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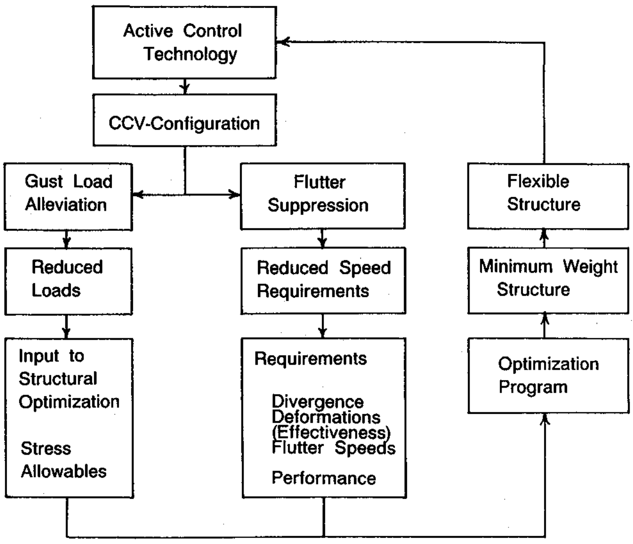


Fig. 2 New technologies of recent aircraft.

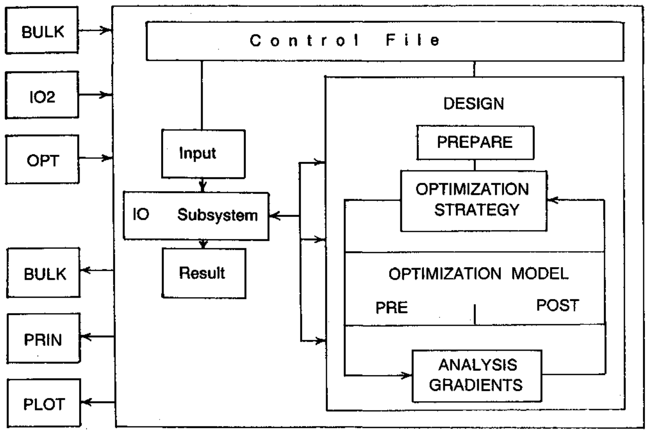


Fig. 3 Program architecture of MBB-LAGRANGE.

addition to stress, displacement, aeroelastic, and dynamic constraints, an integrated design involves all these techniques and the optimization procedures must be extended for these new constraints. A reliable optimization code is the basis that allows parametric investigations and weight penalties to be evaluated.

## III. Structural Optimization at MBB

The performance and requirements/constraints of this new program system are presented:

A finite element structure is a requirement. The structure variables used are skin thickness, balance masses, fiber directions, and grid point coordinates.

Constraints to be fulfilled are min/max—variable, stresses, strains, deformations, flutter speed, divergence speed, aeroelastic efficiencies, eigenfrequencies, element stability, dynamic response, and weight.

A multiobjective function, i.e., vector optimization = "tradeoff" studies of convex combination of objectives can also be treated.

The program architecture is organized due to the concept of Eschenauer[5] with the main parts being optimization algorithm, optimization model, and structural analysis, including sensitivity analysis.

The corresponding optimization models are based on the general nonlinear programming problem.[5] The design variables $x$ are cross-sectional areas of trusses and beams, wall thicknesses of membrane and shell elements, laminate thicknesses for every single layer in composite elements, or nodal coordinates for geometry optimization problems. The constraints in form of inequalities may be any limitation of displacements, stresses, strains, buckling loads, aeroelastic efficiencies, flutter speed, divergence speed, natural frequencies, dynamic response, and design variables.[6]

In the case of scalar optimization, the objective function $f(x)$ often includes the structural weight or another linear combination of the design variables. However, it is also possible to define one of the constraint functions as objective, and to introduce the weight as constraint at the same time. If vector optimization problems are under consideration, then optimization strategies $p[f(x)]$ according to Ref. 5 ensure the transformation to scalar substitute problems.

It is necessary to provide several different optimization algorithms, because there is no known single algorithm which is appropriate to solve all kinds of problems. The following mathematical programming methods are implemented in LAGRANGE: penalty methods, e.g., inverse barrier function (IBF); augmented Lagrangian method, i.e., method of multipliers (MOM); sequent linear programming (SLP); stress ratio method (SRM); recursive quadratic programming (RQP1, RQP2); generalized reduced gradients (GRG); sequential convex programming (SCP), e.g., convex linearization (CONLIN).

The structural and sensitivity analyses are based on FEM. Static, buckling, dynamic aeroelastic, and flutter modules have been incorporated. It is possible to treat homogeneous materials with isotropic, orthotropic, or anisotropic behavior, as well as fiber-reinforced composite materials. The element library contains the types; truss, beam, membrane (3, 4 nodes), shell (3, 4 nodes) elements. In addition, shell structures can be analyzed with a special transfer procedure. This transfer matrix procedure transforms the transfer matrices to a stiffness matrix that can be assembled together with the remaining finite element stiffness matrices. This mixed procedure allows very efficient analyses of large structures including shells taking into account the complex boundary conditions of the shells.

The program architecture of MBB-LAGRANGE, shown in Fig. 3, has a modular setup with defined interfaces. While the modules INPUT and RESULT are used to enter data or to process the results, the real optimization calculation takes place in the DESIGN module. There we have a strong separation between optimization and analysis. The "mathematics" is mostly located in the part-optimization algorithm. The "physics," that stands for the structural response and its derivatives, are realized in the analysis and gradient module. The link of both is the optimization model.

An interactive user exit with an integrated knowledge-based system supports all phases of optimization runs. Further possibilities, like the automatic preparation of batch procures for different hardware systems and the automatic linking dependent on the problem size, ensure high user comfort. Standard interface enables the interaction in the CAE-environment (NASTRAN, I-DEAS, PATRAN). The graphical input of some optimization data saves a lot of time and is really helpful, e.g., variable linking, buckling fields, and displacement constraints.

In order to illustrate the tremendous effort which had to be spent to achieve good mathematical descriptions of the structure, while still being able to simultaneously fulfill several boundary conditions, the derivation of the static aeroelastic module is shown.

## IV. Iterative Solution of Large Linear Equation Systems for Static Aeroelastic Problems

There is a tendency in structural analysis towards systems with increasing numbers of elements and degrees of freedom (DOF). This is caused by the technological demand for exact descriptions of local structural details, and it is possible at the present time with computer sizes and costs.[7]

For this reason, the aerodynamic models and solution methods for aeroelastic problems are adapted to finite element methods. That means solutions in the structural system. But in contrast to pure static problems, the aerodynamic loads matrix is almost fully populated and unsymmetric. A direct solution method is no longer efficient in storage size and computing time, and should be replaced by an iterative method.

When the mathematical method for LAGRANGE was selected the driving considerations were 1) low computer storage space, 2) low time consumption, and 3) applicability for various problems.

In static aeroelastic problems, the aerodynamic load depends on the deformation of the structure. The load vector is composed of a part that depends on the solution and one that is independent of it. Thus, the problem can be expressed as a static equilibrium with $n$ DOF.

$$K \cdot u = b_0 + \boldsymbol{b}(\boldsymbol{u}) \tag{1}$$

with

$$K \in R^{n \times n}, \qquad u, b_0, b \subset R^n$$

$K$ is an $n \times n$ stiffness matrix that is symmetric, positive definite, skyline organized, and a CHOLESKY-factorization is possible. This decomposition can be performed with vectorized algorithms to save time and space. That means, that during the iterations equation, systems with new right sides are solved.

In aeroelasticity, the aerodynamic influence can often be expressed in linear relations.[11] Therefore, the vector $\boldsymbol{b}(\boldsymbol{u})$ can be expressed as

$$\boldsymbol{b}(\boldsymbol{u}) = C \cdot u, \qquad C \in R^{n \times n} \tag{2}$$

This matrix $C$ contains all physical properties, like the dynamic pressure, and all required transformations from the aerodynamic to the structural system. Using Eq. (2), Eq. (1) can be rewritten as

$$(K - C)u = b_0 \tag{3}$$

If the difference $K - C$ is regular, Eq. (3) can be solved. Because the direct solution of Eq. (3) as well as the calculation of $C$ is not favorable, another approach is required.

An iteration process for the solution of Eq. (3) is defined in Eq. (4), where an additional relaxation process is introduced to improve convergence:

$$Ku^{(m+1)} = \omega C u^{(m)} + (1 - \omega) K u^{(m)} + \omega b_0 \tag{4}$$

where superscripts $m$, $m + 1$ embedded in parentheses represent the $m$th iteration step. This equation corresponds with the following eigenvalue problem (5):

$$[\omega C + (1 - \omega) K - \lambda_t(\omega) K] w = 0 \tag{5}$$

The convergence of the iteration strongly depends on the dominant eigenvalues $\lambda_t(\omega)$. The eigenvalue $\lambda_{ti}(\omega)$ is derived by the transformation

$$\lambda_{ti}(\omega) = \lambda_i(\omega) - \omega + 1, \qquad i = 1, 2, \ldots, n \tag{6}$$

where $\lambda_i$ are the eigenvalues of the untransformed case ($\omega = 1$). Because the matrix $C$ is unsymmetric, real and conjugate complex eigenvalues $\lambda_i$ and $\lambda_{ti}$ appear. The eigenvector $w$ remains unchanged by the transformation. Some possible graphs of $\lambda_t$ vs $\omega$ are plotted in Fig. 4. An approach for finding optimal values of $\omega$ (for small $\lambda_t$) is also indicated in this figure.

An explicit calculation of eigenvalues and -vectors is impossible in most cases. But it can be shown that the flow of

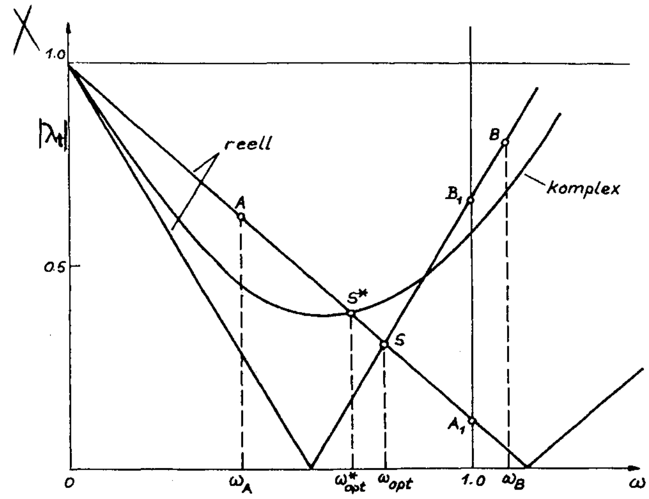


**Fig. 4 Dominant eigenvalues as a function of the transformation variable $\omega$.**

the iteration allows for the deduction of dominant eigenvalues. This is in Ref. 7. If the matrix for all eigenvectors of Eq. (5) is regular, the solution $u$ and the initial solution $u^{(0)}$ can be expressed as linear combinations of eigenvectors:

$$u = W \cdot d \tag{7}$$

$$u^{(0)} = W \cdot d^{(0)}, \quad u^{(0)} \neq u, \quad W \subset C^{n \times n}, \quad d, d^{(0)} \in C^n \tag{8}$$

After a certain number of transformations of Eq. (4), full description is given in Ref. 7, and by means of the assumptions Eqs. (7) and (8) an approximation of the solution could be obtained after interation step $m$

$$u^{(m)} = u - \sum_{k=1}^{n} \lambda_{tk}^m [d_k - d_k^{(0)}] w_k \tag{9}$$

where $d_k$ and $d_k^{(0)}$ denote the $k$th components of the vectors $d$ and $d^{(0)}$, respectively, whereas $w_k$ denotes the $k$th eigenvector, i.e., the $k$th column of matrix $W$. Superscript $m$ without parentheses is used as an exponent.

The values $\lambda_{tk}$, $d_k$, $d_k^{(0)}$, and the eigenvector $w_k$ do not depend on the number of iterations $m$. For a chosen approximation $u^{(0)}$, the iteration process is determined. The summation terms in Eq. (9) vanish for $m \to \infty$, if

$$|\lambda_{tk}| < 1, \qquad k = 1, 2, \ldots, n \tag{10}$$

This allows one to extract the difference of two consequent iteration steps

$$\begin{aligned} \Delta u^{(m+1)} &= u^{(m+1)} - u^{(m)} \\ &= \sum_{k=1}^{n} \lambda_{tk}^m Z_k, \qquad z_k \in C^n \end{aligned} \tag{11}$$

where

$$z_k = (1 - \lambda_{tk})[d_k - d_k^{(0)}] w_k \tag{12}$$

Equation (11) can be used to analyze the iteration. For the following considerations, it is assumed that eigenvalues are in a descending order, and nondominant eigenvalues do not affect $\Delta u^{(m+1)}$ for sufficiently high values of $m$. This leads to three main cases.

1) One single dominant eigenvalue exists for a certain $\omega$ in this case. Equation (11) is used for any components $j$ to form

$$\lambda_{t1} = \Delta u_j^{(m+2)}/\Delta u_j^{(m+1)} \tag{13}$$

The eigenvalue can be transformed back with Eq. (6). If point $S$ in Fig. 4 is only determined by real dominant eigenvalues, a proper selection of $\omega$ allows one to find points $A$ and $B$. For $\omega = \omega_{opt}$, two dominant eigenvalues will appear with different signs.

2) In this case, one additional iteration is used for the following equation:

$$\Delta u_j^{(m+3)} = \lambda_{t1}^2 \Delta u_j^{(m+1)}, \qquad j = 1, 2, \ldots, n \tag{14}$$

to obtain the two eigenvalues $\lambda_{t1}$ and $\lambda_{t2} = -\lambda_{t1}$ for any component $j$. If Eq. (13) is used for all iteration steps, case 2 will deliver a sequence of alternating identical values, depending on $m$ being even or odd.

3) In the case of a conjugate complex pair of eigenvalues, their extraction is much more difficult. The real difference $\Delta u^{(m)}$ in this case is the sum of two complex products with changing real parts:

$$\Delta u^{(m)} = \lambda_1^m z_1 + \lambda_1^{*m} z_1^* + 0(\lambda_3^m) \tag{15}$$

Assuming that only one pair of conjugate complex eigenvalues is dominant, the substitution

$$\lambda_1 = \lambda' + i\lambda'', \qquad \lambda_1^* = \lambda' - i\lambda'' \tag{16}$$

is used to derive the following relations:

$$\Delta u^{(m+2)} = 2\lambda' \Delta u^{(m+1)} - (\lambda'^2 + \lambda''^2)\Delta u^{(m)} \tag{17}$$

$$\Delta u^{(m+3)} = 2\lambda' \Delta u^{(m+2)} - (\lambda'^2 + \lambda''^2)\Delta u^{(m+1)} \tag{18}$$

The only problem here is to determine that a sequence of this type of values exists after $m$ steps. To perform iterations for several values of $\omega$, for the optimal case with a preselected accuracy, is an acceptable compromise in this case.

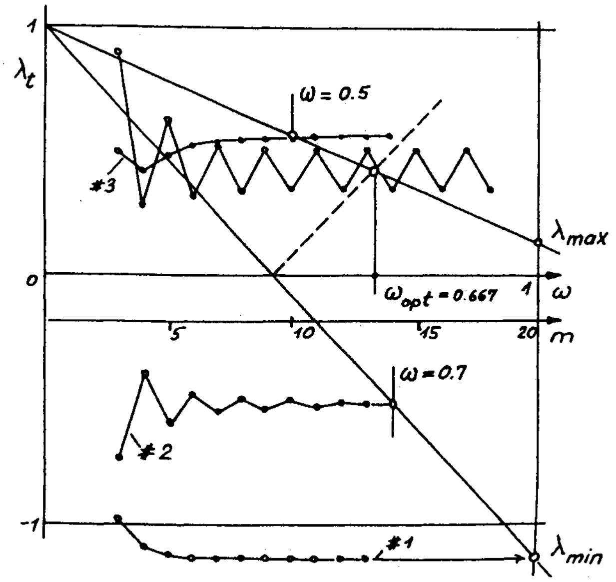


**Fig. 5 Dominant eigenvalues vs $\omega$ and results of iterations for individual steps $m$.**

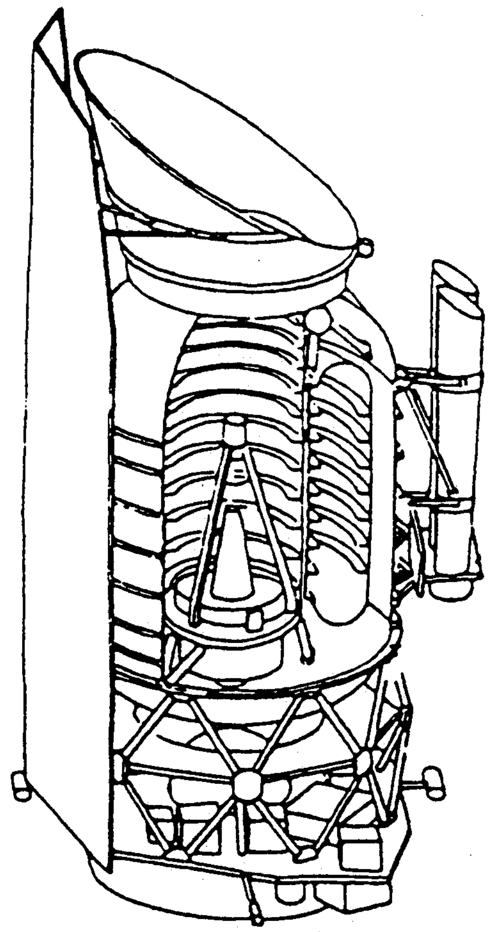

**Fig. 6 Infrared space observatory satellite (ISO).**

In the case of optimization, the required calculation of gradients leads to a solution of the transposed problem in static aeroelasticity

$$K \cdot y = C^T \cdot y + f, \qquad y, f \in R^n \tag{19}$$

with many right side $f$. Analog Eq. (11), the following expression is formed:

$$\Delta y^{(m+1)} = \sum_{k=1}^{n} \lambda_{tk}^m s_k \tag{20}$$

Vector $s_k$ is obtained by the corresponding left eigenvectors.

Although the eigenvalues of the transposed problem are the same as in the untransposed case, the iteration can show a different course—especially during the first steps—because $z_k \neq s_k$. This can cause a difference in the required number of iterations for the same accuracy.

These three cases show that solutions can always be found in automated procedures and restarts are not necessary.

As an example, a realistic structure was investigated with different values for $\omega$. Figure 5 shows the iterations for $\omega$ = 0.5, 0.7, 1, and $\omega_{opt}$ = 0.667. Graph 1 for $\omega$ = 1 shows convergence for the eigenvalue $\lambda_{min}$, but the solution itself did not converge because $\lambda_{min} < -1$ violates the convergence condition. A check with $\omega$ = 0.7 (no. 2) yields $\lambda_{min}$ again after the backward transformation. For $\omega$ = 0.5 the maximal eigenvalue $\lambda_{max}$ is obtained (no. 3). With $\omega_{opt}$, the sequence of alternating identical values of case 2 was obtained. All iterations show a progress during the initial steps that is different from the dominant values because of the contributions of the nondominant eigenvalues and eigenvectors.

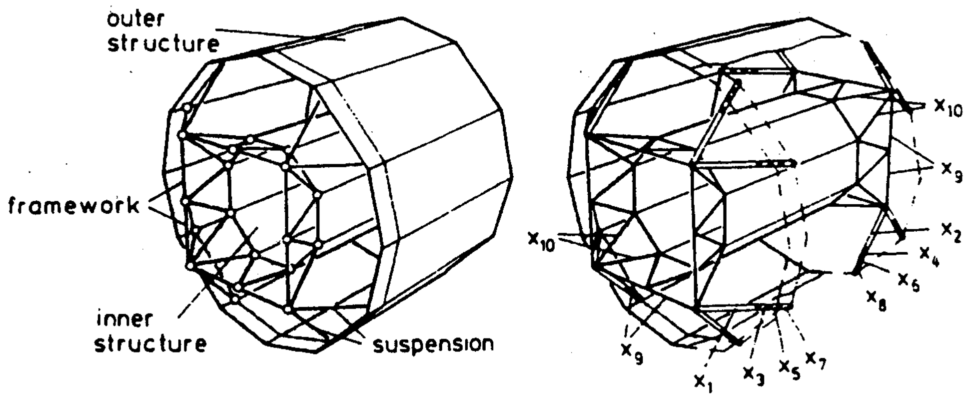


Fig. 7 Finite element model and design variables of the ISO satellite.

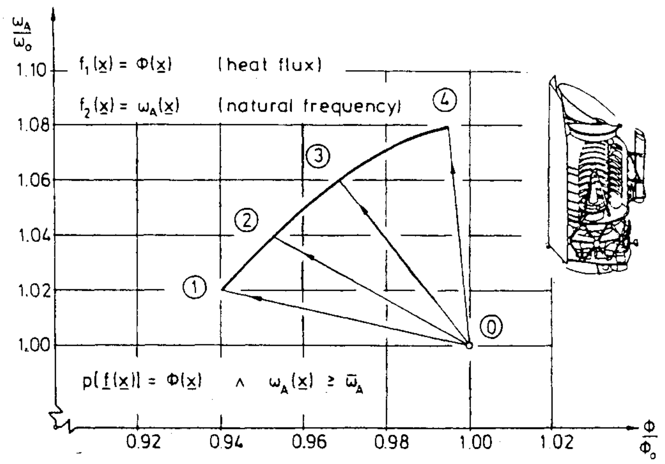


Fig. 8 Boundary of functional efficient solutions for the ISO satellite.

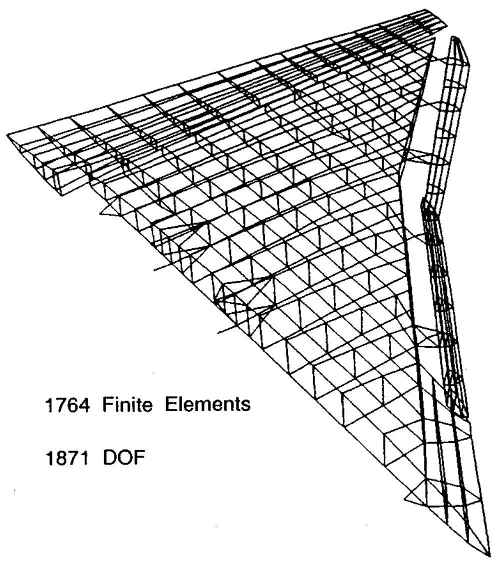


Fig. 9 Finite element model of the X-31 wing.

## V. Applications

### A. Heat Flux and Frequency Optimization of a Satellite Structure

For spacecraft structures, usually two different operating phases are most decisive. During launching phase the dynamic loads dominate. On the other hand, the following mission in orbit is characterized by thermal effects. Thus, an objective conflict occurs, because none of the possible designs permits a simultaneous optimal fulfillment of dynamic and thermal objectives. Here, vector optimization methods are suitable for determining a unique optimal compromise solution.

The ISO-satellite, the European infrared space observatory, will be used to explore cosmic infrared radiation (Fig. 6).

In order to maximize the lifetime of the satellite, the heat flux from the outer to the inner structure, which contains a cooling mechanism for a special sensor, shall achieve a minimum value. Secondly, the natural frequency $\omega_A$ of the dominant axial vibration mode is to be maximized.

The objective function vector $f(x)$ includes the heat flux $\Phi(x)$ and the frequency $\omega_A(x)$

$$f(x) = \begin{bmatrix} f_1(x) \\ f_2(x) \end{bmatrix} = \begin{bmatrix} \Phi(x) \\ -\omega_A(x) \end{bmatrix} \tag{21}$$

where

$$\max \omega_A(x) = \min[-\omega_A(x)] \tag{22}$$

In the sketch of the structural model (Fig. 7), it can be seen that the inner and outer structure are linked by means of a spatial framework and suspensions.

The cross-sectional areas of the supporting framework are defined as the design variables (Fig. 7). As previous studies have shown, the heat flux $\Phi$ can be treated as a linear function of these design variables. Corresponding checks for the initial and optimal designs confirm this approach.

$$\Phi(x) \sim c_0 + \sum_{i=1}^{n} c_i x_i \tag{23}$$

$$\frac{\partial \Phi}{\partial x_i} \sim c_i \tag{24}$$

where the coefficients $c_0$ and $c_i$ are calculated in advance by a heat transfer program.

The natural frequency $\omega_A$ results from eigenvalue problems of a finite element model (212 elements and $n = 672$ DOF)

$$[K(x) - \omega^2(x)M(x)]q(x) = 0 \tag{25}$$

with $K$ and $M$ being stiffness and mass matrices, and $q$ the eigenvector solution, associated with the eigenvalues $\omega^2$. Special regard to the axial vibration mode is necessary during the whole optimization process since the current number of the corresponding frequency $\omega_A$ can change within the frequency spectrum $\omega_k$ ($k = 1, 2, \ldots, n$). It has to be checked within every iteration step and, if required, it needs to be adapted.[8]

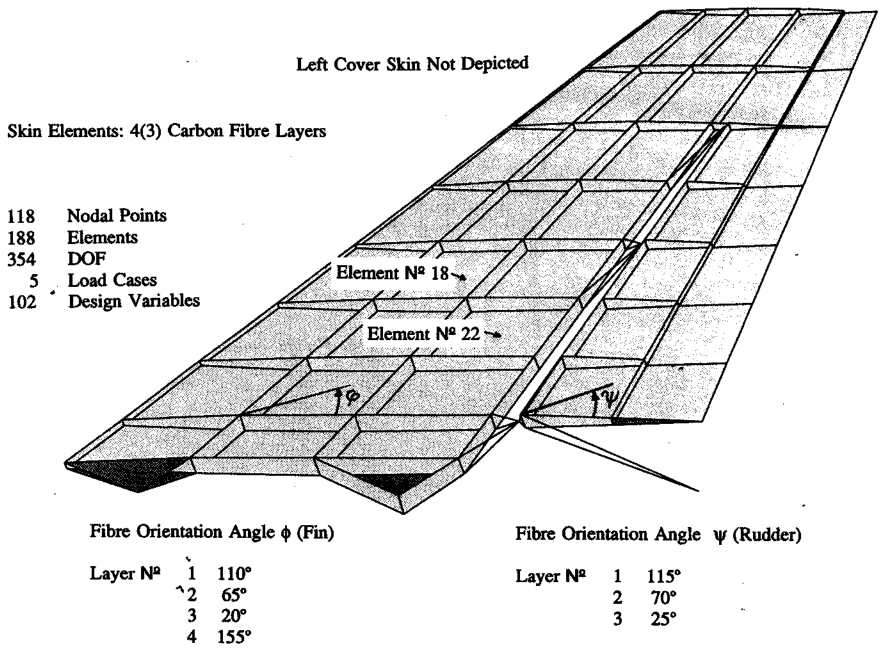


**Fig. 10 Fin structural model.**

**Table 1 Analysis results for initial and optimized design**

| Constraints | Design: Initial | Design: Optimized | Violation, % |
|---|---|---|---|
| Strength | | | |
| Loadcase no. 2 | — | — | — |
| Layer no. 2 | — | — | — |
| Element no. 18 | — | — | 12.3 |
| Element no. 22 | — | — | 22.4 |
| Flutter speed, m/s | 495.0 | 530.0 | 6.6 |
| Effectiveness | | | |
| Fin | 0.753 | 0.814 | 5.9 |
| Rudder | 0.441 | 0.500 | 11.8 |
| Unconstraint values | | | |
| Modal frequencies, Hz | 8.90 | 9.20 | — |
| | 29.83 | 30.61 | — |
| | 31.16 | 30.21 | — |
| | 39.97 | 41.08 | — |
| | 54.86 | 58.31 | — |
| Flutter frequency, Hz | 21.22 | 22.00 | — |
| Weight, kg | | | |
| Structure | 99.40 | 92.40 | — |
| Nonstructure | 53.60 | 53.60 | — |
| Total | 153.00 | 146.50 | — |

The derivatives of the natural frequency $\omega_A$ with respect to the $i$th design variabler $x_i$ $(i = 1, 2, \ldots, n)$ are as follows:

$$\frac{\partial \omega_A}{\partial x_i} = \frac{1}{2\omega_A} q_A^T \left( \frac{\partial K}{\partial x_i} - \omega_A^2 \cdot \frac{\partial M}{\partial x_i} \right) q_A \tag{26}$$

By means of a constraint-oriented transformation (tradeoff) this vector optimization problem (VOP) is reduced to a scalar optimization problem (SOP).[9] The heat flux $\Phi$ is minimized as main objective and the frequency $\omega_A$ has to achieve different constraint levels to get different functional efficient solutions. For this optimization problem, with one dominant constraint, the recursive quadratic programming (RQP) algorithm shows good efficiency.[5]

The initial design has a nondimensional heat flux of $\Phi = 1$ and a nondimensional frequency of $\omega_A = 1$. Dependent on the selection of appropriate constraint levels for the frequency, one gets different optimal compromise solutions. The functional efficient boundary (Fig. 8), delivers a good foundation for the selection of a final design. Here the design with $\Phi = 0.99$ and $\omega_A = 1.08$ is chosen.[9]

### B. Design of a Carbon Fiber Wing

The wing structure for the experimental aircraft X-31A was optimized with LAGRANGE. In this case, optimization was beneficial for two main objectives of the program; a low-cost approach and a very short time for development and design. Besides a design for minimum weight, another requirement was a high flutter margin to reduce efforts and costs for flutter wind-tunnel and flight tests. Although flutter did not affect the design, it could be surveyed simultaneously during optimization. Static aeroelastic effectiveness was also investigated during the design process.

A finite element model of the wing is depicted in Fig. 9. It has 1764 elements and 1871 DOF. The optimized skin thicknesses were then translated into design drawings with small modifications. As an example, the upper wing skin weight of 53 kg from an initial design (preoptimized with another program) could be reduced to 44 kg in the FEM, which resulted in 45 kg in the actual design. The final design meets the target weight and has a margin of 100% in airspeed for flutter.

### C. Aeroelastic Tailoring of a Fin Made of Composite Material

An aircraft fin has to fulfill quite different design requirements with a similar priority, and the final design requires the evaluation of many off-design point studies.[10]

The design of aerodynamic surfaces such as wing, fin, foreplane, and tailplane needs two major design steps:

1) The aerodynamic design to define the overall geometry like area, span, aspect ratio, taper ratio, and profile, mainly camber angles.

2) The structural design to develop the internal structural arrangement of skin, ribs, stringers, spars, rudder support, rudder actuation, attachments, equipment systems.

The final design must fulfill design requirements with minimum weight: static strength to withstand design loads, aeroelastic efficiencies for performance, no flutter inside of the flight envelope, and manufacturing constraints such as min and max gauges. It is quite clear that such a design requires an interactive coupling of the above-mentioned two design steps. A structural model of the investigated fin is shown in Fig. 10. A comparison of analyses results for both initial and

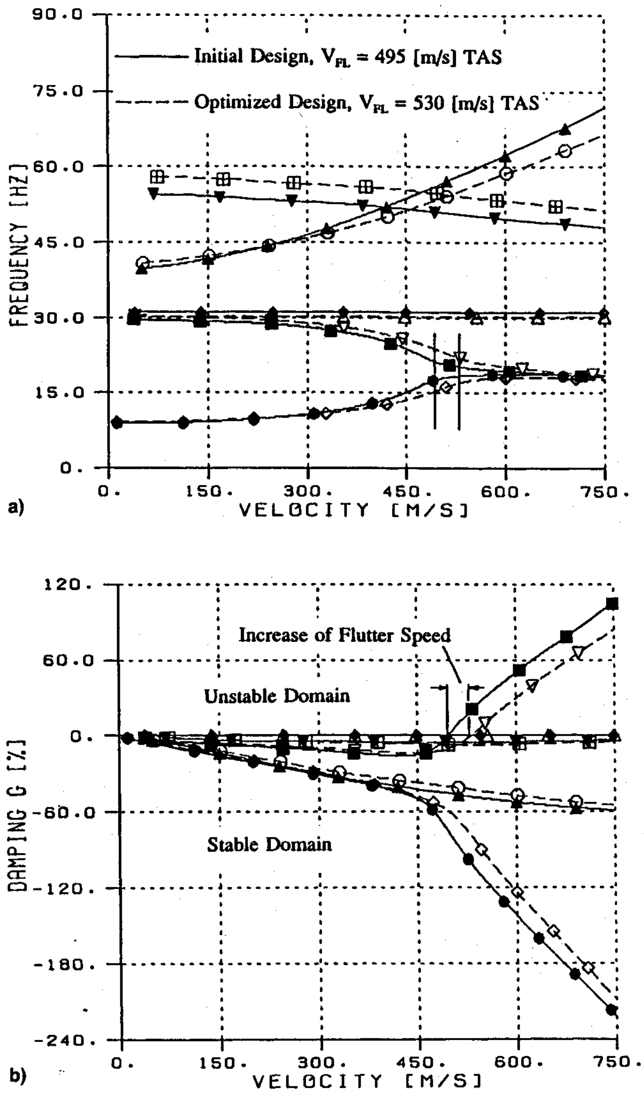


Fig. 11 Flutter analysis $v$-$g$ plot.

optimized design is given in Table 1. From this table it could be seen that in spite of the constraint violations, e.g., flutter speed (6.6%), fin effectiveness (5.9%), rudder effectiveness (11.8%), element strain (12.3, 22.4%) the structural weight was reduced by 7% using the optimization procedure LAGRANGE. Furthermore, a mode exchange in view of frequency sequence could be recognized. During the whole optimization process "mode tracing" was necessary since the modal frequency of the second mode increases from 29.83 to 30.61 Hz, whereas that of the third mode decreases from 31.16 to 30.21 Hz.

Figs. 11a and 11b show the results of the flutter analyses for the initial design (solid lines) and those for the optimized design (dashed lines). From the frequency plot it can be seen that the optimization process yields a remarkable frequency separation of the first and second mode near the flutter point. The corresponding damping plot shows the increase of the flutter speed. For the initial design the unstable domain—with damping values greater than zero—was reached at 495 (m/s) TAS, whereas the optimization process delivered a flutter speed of 530 (m/s).

## VI. Conclusions and Future Work

Further development of MBB-LAGRANGE will be concentrated on the introduction of additional analysis options, computing cost reducing approximation procedures, and new structural constraints including heat transfer and thermal stresses, new routines for buckling and global stability, dynamic response, effect of FCS on structural phenomena, geometry optimization (fiber direction, position of spars), effect of changed loads throughout optimization, integration of new disciplines, combination of different objective functions, and new optimization routines.

For the future, it is a challenge in aerospace engineering to combine design variables, requirements, objectives, and constraints from different disciplines in one optimization program. But it cannot be expected and is not desired that there will be only one program for the optimal design of aircraft.

An initial preliminary design should include as many disciplines as possible. But at the same time, this task must remain in a not too detailed and complex level to allow the investigation of a great number of designs, and to answer questions concerning essential changes of design requirements in a relatively short period of time.

After this, the individual disciplines should use their own programs and methods to find the optimum in a more detailed model, without forgetting the neighbor areas.

The preliminary design program could in parallel serve as a tool to integrate the results from detail designs.

Large efforts will be required to reduce the enormous computational costs by the development of efficient methods for cross sensitivity calculations and for approximate optimization procedures.

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