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FINAL TECHNICAL REPORT

November 1975

Grant NGR 52-012-008

Automated Wing Structural Design

(NASA-CR-147142) AUTOMATED WING STRUCTURAL DESIGN Final Technical Report (Technion - Israel Inst. of Tech.) 12 p HC $3.50 CSCL 01A

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Department of Aeronautical Engineering

Technion - Israel Institute of Technology

Haifa, Israel

Principal Investigator: Dr. Raphael T. Haftka

(Now at Illinois Institute of Technology, Chicago, Illinois)

ABSTRACT

This report summarizes the work done under NASA grant NGR 52-012-008, entitled Automated Wing Structural Design. The work was done during the period of December 1973 to October 1975.

The main thrust of the effort under the grant is research on the optimization of wing structures under multiple constraint such as strength, displacement, buckling, flutter and divergence limits. Advances were made in improving mathematical programming techniques as well as in improving the efficiency of constraint calculation. The WIDOWAC (Wing Design Optimization With Aeroelastic Constraints) computer program served as the main vehicle for this research. However, as this program is a research program some effort was directed to implement the methods developed in this work in a general user oriented finite element program. This effort is expected to be pursued vigorously in the future.

INTRODUCTION

Current techniques for automated structural design, such as the fully stressed design method, handle well the design for strength of stiff structures under mechanical loads.

For flexible wing structures such techniques often prove inadequate because of two reasons. First, the design of most wing structures is determined by other constraints such as static and dynamic aeroelastic constraints, control effectiveness constraints, and buckling constraints. Second, the external loads on the wing often depend strongly on the thickness of the structural elements (aeroelastic and thermal loads) which are commonly used as design variables.

The need to tackle various design constraints has resulted in design techniques which are suitable for specific constraints. Thus there are methods tailored for stress and displacement constraints, methods tailored for flutter constraint, ans so on. Mathematical programming methods, on the other hand, afford the generality that permits simultaneous design for a multitude of constraints. The disadvantage of the mathematical programming approach is that it requires a large number of analyses to be performed. New mathematical programming techniques which require a smaller number of analyses, and efficient methods of reanalysis help overcome this disadvantage.

The work done under NASA grant NGR 52-012-008 was directed towards these twin goals of better mathematical programming techniques and more efficient structural analysis methods. The main vehicle for implementing the research effort was the WIDOWAC (Wing Design Optimization With Aeroelastic Constraints) computer program (Ref.1) developed by the principal investigator at NASA Langley Research Center during his stay there on an NRC associateship.

Since most of the results of the research performed under the grant are published as journal or conference papers this report is limited to a short description of the work with appropriate references to the published papers.

I. Optimization Methods

a. Mathematical Programming

The optimization method used for the WIDOWAC computer program was the Sequence of Unconstrained Minimization Technique (SUMT) utilizing an interior penalty function. Newton's method with approximate second derivatives (Ref. 2) was used for each unconstrained minimization. Even though this optimization method is very efficient compared to other mathematical programming methods it was still costly enough to limit the capability of the program to 10-20 design variables. To improve the optimization method three steps were taken. These are described in detail in Ref. 3 and summarized here.

1. Approximate techniques were used for avoiding a full scale analysis at every design point along a search direction.
2. Analytical derivatives of stresses, displacements and buckling loads were used for saving time in computing search directions and as a basis for the approximate analysis.
3. To make it possible to use efficiently approximation concepts a new quadratic extended interior penalty function was developed and implemented in WIDOWAC. The use of an extended penalty function permits efficient recovery from excursions into the unfeasible design domain caused by the use of approximation techniques. The use of a quadratic extension for the

penalty function rather than the more common linear extension was mandated for compatibility with the second order Newton method.

The improved optimization procedure was implemented in a version of WIDOWAC that can handle stress, displacement, buckling and minimum gage constraints. The improved capability is reflected in some of the examples in Ref. 3 including a 147 design variables 201 degrees of freedom wing structure.

b. Optimality Criteria

Though the main thrust of the work under the grant was on an optimization procedure based on mathematical programming methods, some work was done in the area of optimality criteria based algorithms. The research reported in Ref. 4 was partly funded by the grant, and it involved a comparison between mathematical programming and optimality criteria based methods for wing design under flutter constraints. An efficient resizing method was developed that is based on the optimality criteria for flutter constraints. When the only important constraint in the design is flutter the algorithm developed should prove to be very useful. Ref. 4 is a conference paper, it was also accepted for publication in the AIAA journal.

II. Constraint Evaluation

The goal of improved efficiency in the computation of displacements, stresses, flutter speeds and other constraints has been achieved through two measures. The first is improved method of analysis for each constraint and the second is use of approximation to the constraints during parts of the optimization cycle. This section summarizes these twin techniques as applied to the individual constraints.

a. Flutter Constraints

The first step in developing an efficient flutter analysis capability was to separate the parts of flutter analysis which depend only on the wing planform from the parts that depend on the structure of the wing. The former have to be done only once during the optimization process and the latter repeated. One of the most important questions in this regard was the most efficient use of vibration modes for the structural representation. Specifically, how often should these modes be calculated. The major part of this work was done before the start of the grant and is documented in Ref. 5. Additional work on this problem is included in a journal version of Ref. 5 accepted for publication in the Journal of Aircraft.

The problem of computational efficiency for the flutter analysis becomes more important because of the discontinuous nature of the flutter phenomenon. Ref. 2 documents an example of discontinuities of the flutter speed as a function of structural member thickness. The problem can be solved by monitoring during the optimization the entire V-g diagram rather than just the flutter point. This, however, is very costly. A major part on the effort under the grant, therefore, was the development of a technique to spot and follow the danger points on a V-g diagram. The technique, documented in Ref. 6, obviates the need to monitor constantly the entire V-g diagram. Rather, only several such calculations are required while most of the time only a few points on the diagram are monitored.

b. Static Aeroelastic Constraints

The calculation of the displacement and stresses on a flexible wing is much more time consuming than such calculation for a rigid wing. The reason is the dependence of the loads on the displacement.

An efficient iterative procedure was developed under the grant for displacement and stress calculation in wings during symmetric pull-up maneuvers. This work is documented in Ref. 7, a paper submitted for publication to the Journal of Aircraft. The paper includes also the development of expressions for the derivatives of the displacements and a demonstration of the efficiency of the method.

Other Constraints

Work under the grant has also included other constraints such as buckling and thermal loads, However, this work has not been completed. It is expected that completion of that part of the work would be followed by documentation in a journal paper or NASA publication in the next year.

III. Program Implementation

The work described in the previous two sections has been implemented in the WIDOWAC program (Ref. 1). This program is a very useful test bed for optimization procedures and it also provides a reasonable design capability, especially for optimization under flutter constraints. It is limited however by severe restriction on the generality of the finite element and aerodynamic models.

Recognizing the need to capitalize on the research effort sponsored by the grant in a more general setting, work has started on incorporating the WIDOWAC optimization procedures in the SPAR program. SPAR is a general finite element code developed by Lockhead with NASA funding. It combines generality with high efficiency which makes it an ideal candidate for design work. The effort under the grant was of a preliminary nature directed to assess the feasibility of tying the two programs together. The study of the SPAR program has led to the conclusion that, indeed, it is possible to combine it with WIDOWAC to produce a general and efficient design code.

ACKNOWLEDGEMENTS

The technical monitor for this grant was Dr. James H. Starnes, Jr. of NASA Langley Research Center. Dr. Starnes participated in the research effort much beyond monitoring it. In effect, a significant part of the work was a cooperative effort of the principal investigator and Dr. Starnes. This is reflected in the authorship of several publications resulting from the effort funded by the grant. Dr. E. Carson Yates, Jr. and Dr. Sidney C. Dixon of NASA Langley Research Center also contributed to this work. The principal investigator also gratefully acknowledges the useful suggestions, excellent editorial help and encouragement of Dr. W. Jefferson Stroud of NASA, Langley Research Center.

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