DESIGN OPTIMIZATION USING COMPUTER TECHNIQUES

Designing an aircraft wing? Here's a unique approach to the optimization of the wing structural box for static loads. The technique employs the latest developments in structural synthesis and analysis and is applicable for both conventional and composite materials.

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SCIENTIFIC computers have long been used in the design and analysis of aircraft wings. However, the method reported herein employs the use of the computer from the basic preliminary lines definition through the stress analysis of the wing structure, with a minimum of human intervention and effort.

Fig. 1 illustrates this optimization process and includes the steps discussed in the following. Wing lines data are generated through the use of an APT procedure which computes the three-dimensional geometry and enters this data on punched-paper tape. This tape, in turn, drives an automatic drafting machine. The geometric data for the structural box section is used in preliminary structural sizing procedures to rapidly evaluate various construction types and spar arrangements. This narrows the selection, such that a selected design can be further examined through the use of a design synthesis procedure which performs a rigorous design optimization of the structural box. The structural data from this design synthesis is then fed into a finite-element procedure which automatically sets up the structural idealization using a methodology similar to that employed in the APT wing lines procedure. This produces a double-precision, linear stress analysis of the wing box and an internal loads distribution, as well as the deflected shape. Depending on the degree of detail desired in the particular study, the design may be further refined through the use of an individual panel design option of the synthesis procedure, or the design process may be stopped at the completion of the analysis.

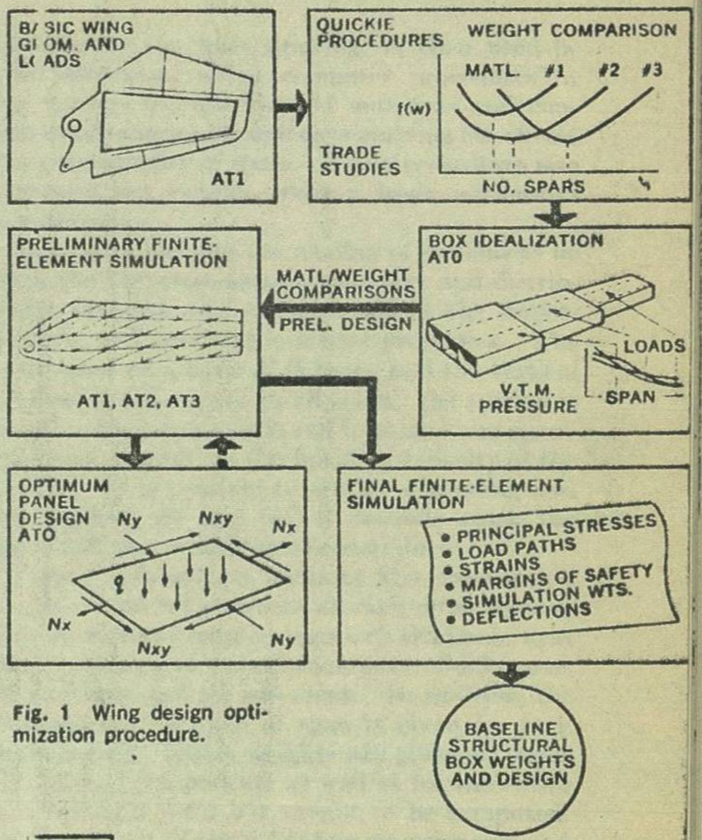

Fig. 1 Wing design optimization procedure.

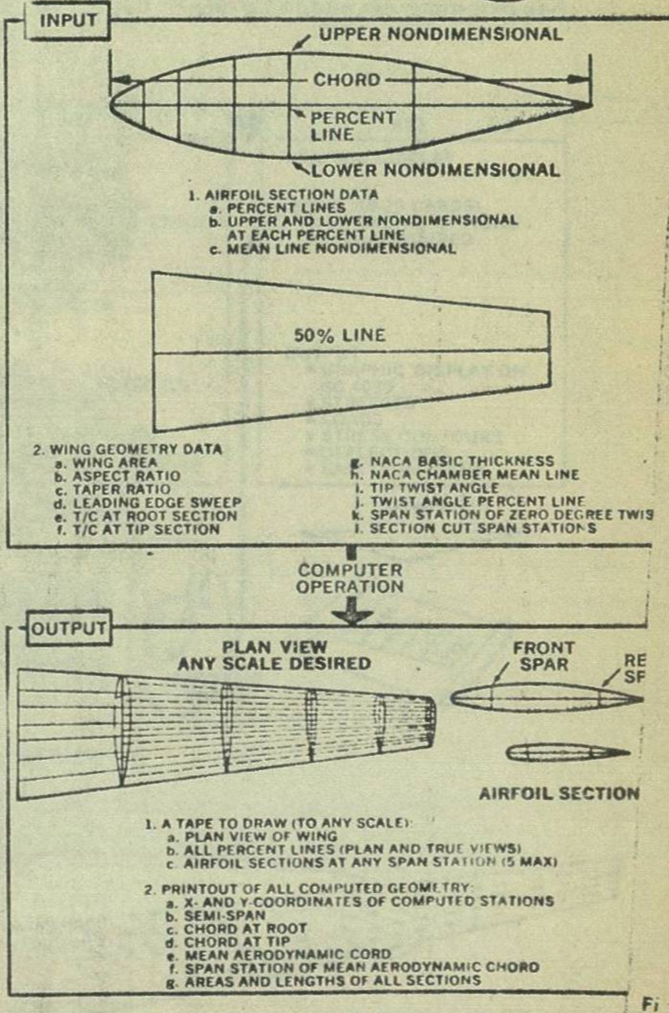

Fig. 2 APT computer procedure.

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Based on a paper contributed by the ASME Design Engineering Division.

APT Procedure

The APT procedure is a generalized program for deriving the numerical data for defining a set of wing lines through the use of a numerically controlled drafting machine. This procedure can handle any wing shape for either variable or fixed wings. Also, it will accommodate wings with different airfoil sections at the root and tip, as well as different thickness-to-chord ratios at root and tip. In addition to these variables, the wing can be both twisted and cambered.

Basic computation is performed by the use of an IBM 360-65. Input to the program is shown in Fig. 2, and includes wing area, aspect ratio, thickness-to-chord ratio at the root and tip, airfoil coordinates at the root and tip, camber and twist, if any, leading edge sweep, front and rear spar location, pivot pin location, if it is a variable-sweep wing, and span stations at which section cuts are desired.

In addition to computing the three-dimensional data and preparing a punched-paper tape for driving a numerically controlled drafting machine, the procedure also computes the cross-sectional and wetted areas of the airfoil section, as well as the cross-sectional area of the structural box between the front and rear spars. This data is presented in conventional printed-paper formats. The information is also available in punched cards or in magnetic-tape form for direct links with computer procedures.

The information from this procedure, either from the printed data or the lines drawing, is then used in simplified structural sizing computer procedures to examine various combinations of materials and construction combinations, as well as evaluating the effects of varying the number of spars. These procedures size the structural box rapidly, using a basic section-by-section approach.

The input data includes the number of sections to be examined, the box cross-section geometry and distributed shear, moment, and torque loads at the respective stations, and pertinent material properties. The covers are sized on a basic M/h basis, and the vertical shear is distributed evenly to all spars; the torsion is distributed to the cover panels and front and rear spars. A rough check is made on the buckling capacity of the upper cover. It is possible to specify a bending and torsional rigidity, EI and GJ, if desired, which the procedures will use as additional constraints.

The output information contains the dimensional data of the structural elements at each cross section, including interior and exterior spar web thickness, spar cap areas, tension and compression cover thicknesses, rib web thickness, and rib cap areas. In addition, the weight in pounds per inch of span is given for each section evaluated. These weights are given in terms of the individual components as well as for the entire section, allowing a total box weight to be computed. Further, the section EI and GJ values are computed and printed.

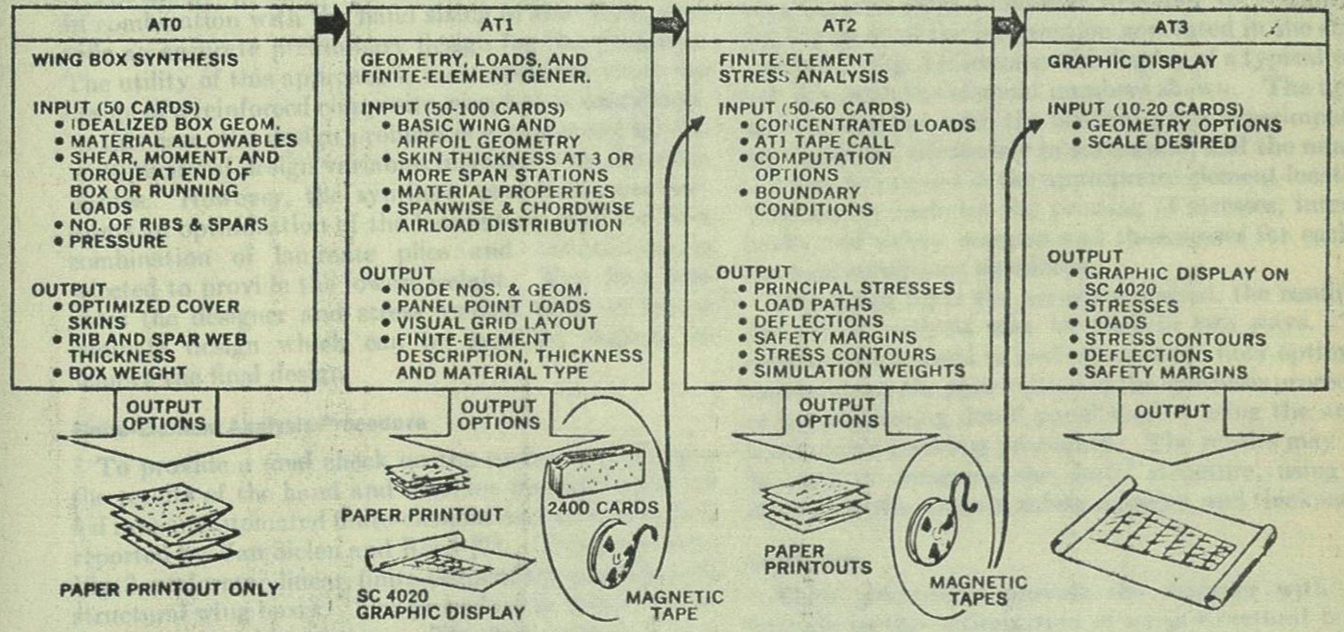
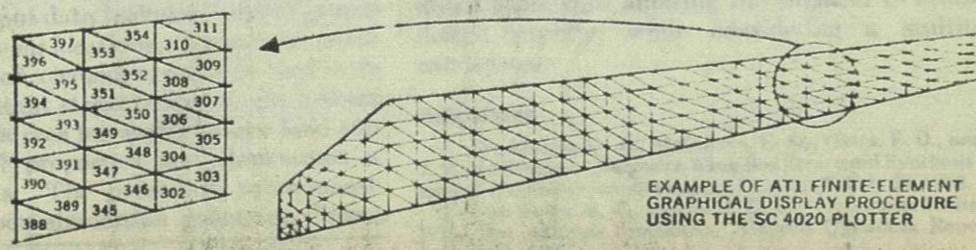


Fig. 3 Wing box synthesis and analysis technique.



EXAMPLE OF AT1 FINITE-ELEMENT GRAPHICAL DISPLAY PROCEDURE USING THE SC 4020 PLOTTER

Fig. 4 Wing finite-element simulation.

The data from these procedures are then plotted in terms of box weight versus the number of spars, thus allowing a rational selection of the number of spars and the arrangement. Also, this information may be compared between different material and construction types to get a close idea of the relative weights.

Once rational selections have been made on construction types and spar arrangements, the selected structural arrangements are then examined in considerable depth through the use of a structural box synthesis procedure reported by McCullers and Waddoups [1].[2] Working with a set box geometry, loads, and spar arrangement, this program will simultaneously optimize the wing box to three distinct load conditions, including constant shear, constant torque, linear bending moment, and internal pressure for each load condition. It is also possible to design the compression cover only; in this mode, the loads may be input as running edge loads (N_x, N_y, and N_{xy}) and the pressure distribution (Q). The program has a built-in anisotropic plate analysis procedure using an assumed mode analysis. In either option, this procedure then develops an optimum design considering 18 design variables. The results from this procedure provide a very good comparison of the different material concepts. The weights are based on optimum load-carrying material only and exclude nonoptimum considerations for edge concepts and concentrated loads, which are usually added through normal hand computations.

The designs generated in the optimization procedure, in combination with the hand sizing of the edges, provide an accurate preliminary design for the wing box. The utility of this approach is most apparent when the design of a reinforced composite wing box is considered. In this case, the design problem is complicated by the multiplicity of design variables introduced by the composites. However, the synthesis procedure also performs an optimization of the laminate in that the best combination of laminate plies and orientations is selected to provide the lowest weight. This then provides the designer and stress analyst with an initial laminate design which can be modified slightly to achieve the final design.

Finite-Element Analysis Procedure

To provide a final check on the preliminary design, the results of the hand and machine computations are fed into an automated finite-element analysis procedure reported by Van Siclen and Reed [2]. This procedure, Fig. 3, performs a linear, finite-element stress analysis of structural wing boxes. The procedure is comprised of three sequential operations. The first procedure is a geometry generation scheme which automatically sets up the simulation of the structure to be analyzed in the second step. Less than 100 cards are required as input data to this procedure. Input data includes: airfoil geometry at the root and tip, spar locations, rib locations, material types to be analyzed, element types to be used in the simulation (bars, constant stress triangles, etc.), shear moment, and torque curves for each of three load conditions, and material properties and thicknesses at discrete span stations. The procedure subsequently generates the wing box simulation geometry, "panel points" each of the three load conditions, and assigns the thickness and stiffness values to the individual elements.

The second step requires approximately 20 input cards defining procedure options and additional discrete concentrated load points. This procedure performs a linear, finite-element stress analysis of the wing box using techniques reported by Blacklock, Richard, and others. The output data can be in the form of printed output, punched cards, or magnetic tape. This data includes node point deflections, internal load distributions on each element, including N_x, N_y, and N_{xy}, stresses on each element including $_x$, $_y$, and $_{xy}$, safety margins, and a weight estimate based on the weight of the structural simulation. As an option, the procedure has the flexibility to examine each element for each of the three load conditions and to ratio the element thickness up or down to get a closer margin of safety. This procedure will analyze all wing types including fixed and variable sweep, twisted and cambered. It also accommodates diverse structural arrangements having both spanwise and chordwise skin thickness variations. Upper and lower skin thicknesses may vary, and both chordwise and spanwise load variations are permitted. The procedure is general enough to be used on any structural box which may be simulated using constant-stress triangles for skins, quadrilateral elements for webs and bar elements for cap members.

The final step in this procedure utilizes the Stromberg Carlson 4020 Computer-Recorder to graphically display most of the information generated in the stress analysis. Fig. 4 illustrates the display of a typical wing box skin with the element numbers shown. The upper and lower skins, with the element grids superimposed, are displayed alternately in succession, and the numerical data is printed in the appropriate element location. The display includes the printing of stresses, internal loads, and safety margins and thicknesses for each of the load conditions simulated.

Depending upon the accuracy desired, the results of this stress analysis may be used in two ways. The results may be used to perform an even finer optimization by using the plate option of the synthesis procedure or by performing detail panel studies using the anisotropic plate buckling procedure. The results may also be used in designing the detail structure, using the internal loads, stresses, safety margins, and thicknesses.

Conclusion

These procedures provide the designer with new latitude in the optimization of wing structural boxes. The procedures have been automated and linked to the extent that they are easy to employ and provide a reduction in both time and laborious preparation of detail data, thus allowing the engineer to establish his design rapidly, while considering a multitude of candidates.

References

1 Waddoups, M. E., McCullers, L. M., Olson, F. O., and Ashton, J. E., "Advanced Composite Wing Box Structural Synthesis Development," General Dynamics Report FZM-5265, Feb. 20, 1969.

2 Van Siclen, R. C., and Reed, D. L., "Automatic Finite Element Wing Box Analysis Procedures," General Dynamics Report FZM-5419, Sept. 1969.

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[2] Numbers in brackets designate References at end of article.