Application of Computer-Aided Aircraft Design in a Multidisciplinary Environment

Robert E. Fulton,* J. Sobieszczanski,† O. Storaasli,‡ Emma Jean Landrum,§ and D. Loendorf¶
NASA Langley Research Center, Hampton, Va.

Theme

THE increasing complexity of advanced aerospace vehicles, together with the decreasing number of similar designs, has established the need for improved ways to utilize the capabilities of computers to support the total design process and to include more detail in preliminary design. A software system intended to meet this need is currently in the definition stage. This system is denoted Integrated Programs for Aerospace-Vehicle Design (IPAD) and a partial description of its over-all goals is given in Ref. 1.

This paper describes results obtained from a small-scale experimental computer aided design system developed at the Langley Research Center as a part of the basic research supporting the IPAD development effort. This system takes into account a limited number of disciplines with a significant depth of detail in each, and represents only a small fragment of the total preliminary design process; however, the results show how the influence of discipline details can be assessed for over-all configuration design. The system (see Fig. 1) is currently composed of three sets of independent self-contained programs denoted operational modules (OM's) and a data base manager to transfer data between modules and a large data base. The total process is controlled by an executive program which interfaces with the user in a user-oriented language.

An aerodynamics module calculates the aerodynamic characteristics of a prescribed configuration. The module is derived from a system of integrated computer programs for supersonic design and analysis[2] which has been used extensively for a number of years and has proven to be a viable tool in the design and analysis of supersonic configurations ranging from transport aircraft to fighters. A structures module obtains the preliminary design of a minimum weight structure within a prescribed configuration utilizing the loads obtained from the aerodynamics module. It carries out an automated preliminary design of the primary structure of a wing and fuselage by combining two independently developed programs,[3,4] both of which use a mixture of fully stressed designs and mathematical optimization methods. A performance module simulates a prescribed flight profile utilizing lift-drag polars from the aerodynamics module and weight from the structures module to determine the resulting vehicle payload. The performance module currently includes within it a gross approximation to a propulsion system defined by engine size factor and number of engines. Flight simulation is obtained by a step-by-step solution of motion of an aircraft whose mass varies as a result of the fuel consumption. Although the modules are currently limited to three disciplines, the system has been designed to be modular and open-ended and additional modules can be incorporated readily as needed.

Contents

The system was applied to a series of trade studies to demonstrate the potential of multidisciplinary design automation in determining optimum designs. With the reference aircraft configuration (Fig. 2) as a starting design,

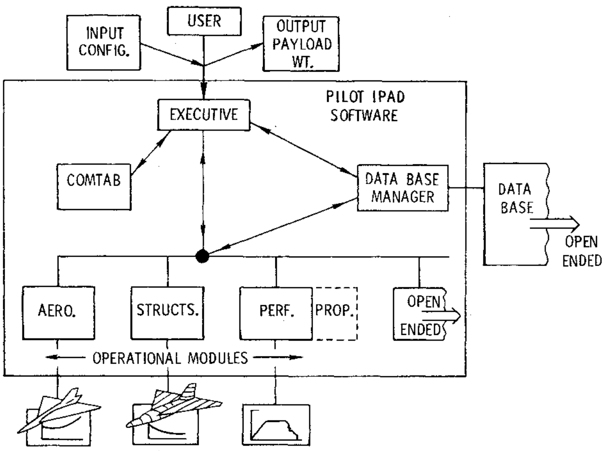

Fig. 1 Diagram of the system software.

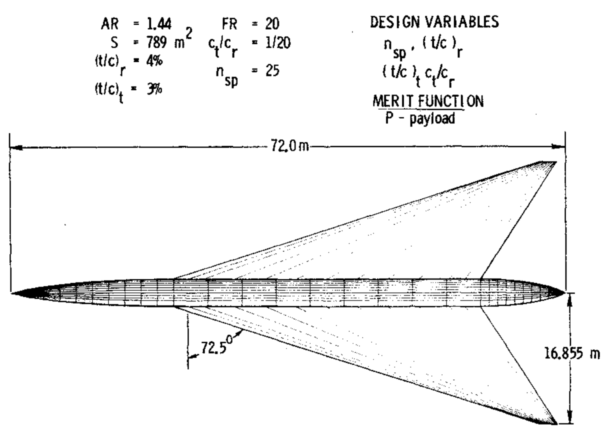

Fig. 2 Reference aircraft configuration. (*AR*, aspect ratio; *S* area; *FR* fuselage length-to-diameter ratio, V_{cruise} = 2.7 M range 3000 nm, TOGW = 750,000 lb, Applied load factor 2.5, safety factor 1.5).

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Index categories: Aircraft Configuration Design; Aircraft Structural Design (Including Loads); Computer Technology and Computer Simulation Techniques.

*Head, IPAD Technology Section, Structures & Dynamics Division. Member AIAA.

†Senior Research Scientist, Structures & Dynamics Division. Member AIAA.

‡Research Scientist, Structures & Dynamics Division. Member AIAA.

§Aerospace Engineer, High-Speed Aerodynamics Division. Member AIAA.

¶Aerospace Engineer. U.S. Army Air Mobility R&D Laboratory. Member AIAA.

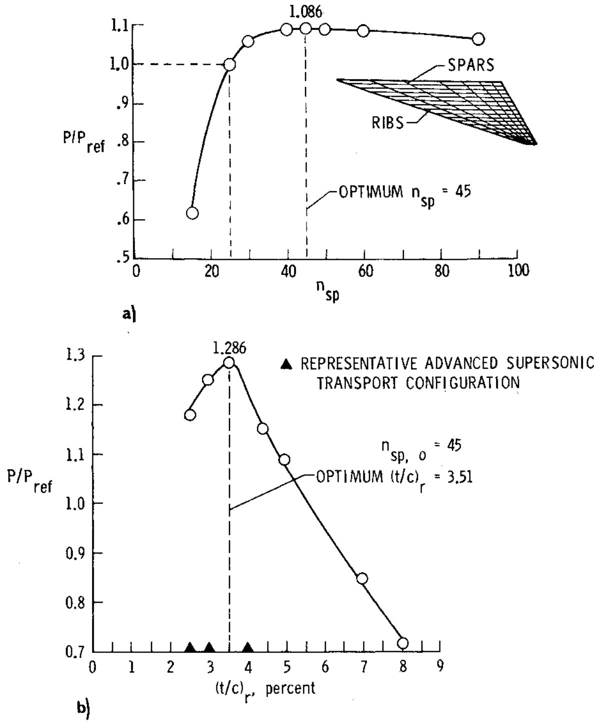

Fig. 3 Payload changes for a sequence of one-dimensional searches. a) Relative payload vs number of spars (Number of ribs held constant). b) Relative payload vs wing root thickness with constant wing thickness taper ratio.

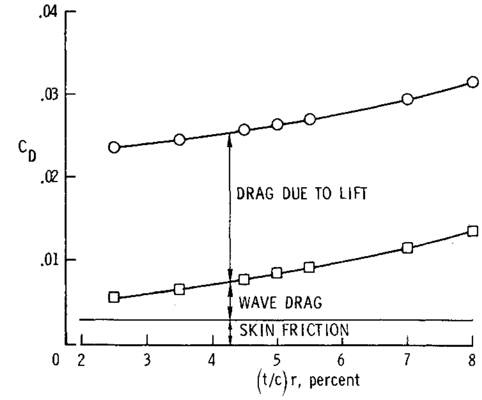

Fig. 4 Effect of wing root thickness on drag for C_L = 1.6.

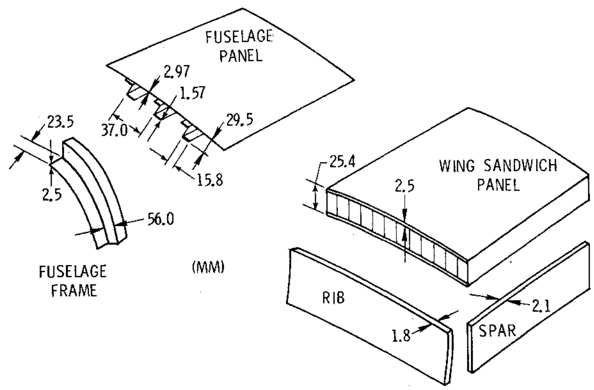

Fig. 5 Example of detailed structural component dimensions output by the structures module (dimensions in millimeters).

the system determined the maximum payload of the configuration as a function of four design variables. The variables included in the study are the number of wing spars (n_{sp}), wing root thickness-to-chord ratio (t/c), wing thickness taper ratio $[(t/c)_t/(t/c)_r]$, and wing chordwise taper ratio (c_t/c_r). Starting with the initial values shown in Fig. 2, the maximum payload design is obtained by a sequence of one-dimensional searches in the four design variable space. The first two of the total of four searches are illustrated in Figs. 3a and 3b, respectively. Such aircraft design studies are usually based on statistical data; however, these results include the effects of technical details of significant depth and, therefore, can be applied to vehicles outside the current design experience.

The sequence of one-dimensional searches (Fig. 3) yields the optimum design if the merit function is quadratic in the design variables. Since the payload variation in the design space is not likely to be quadratic, the process should be repeated until the optimum design is obtained. A practical approach is to test whether the resulting optimum design is very near the maximum. This is done by a sensitivity analysis of the optimum design to determine if the gradients of the payload function are small, indicating that the result is near optimum. Sensitivity analyses for a ±5% change in each design variable were carried out (shown in full paper) and indicated that the last result is very near "the top of the hill." The final design, is, therefore, accepted as the "optimum" design for this study.

The limitation of the number of disciplines herein did not permit the effect of flutter, fatigue, stability, and control, etc., to be felt. Even such effects as the number of spars would be significantly affected by fabrication constraints, wheel well effects, other load conditions, and other layouts. In spite of such limitations, the present results are in reasonable agreement with similar designs (Fig. 3b). Furthermore, for other important effects new OM's can be incorporated in the system through the use of the basic software. A sample of the level of detail of the configuration synthesis is illustrated for typical outputs of the aerodynamic and structures modules by Figs. 4 and 5.

The detailed data obtained for each discipline by an integrated design system such as the one described herein, can permit discipline specialists to better evaluate design concepts and to make judgments on the validity of the design. Such capability broadens the range of design criteria which can be assimilated early in the design process. This system demonstrates the type of information that can be automated in a preliminary design environment and provides an indication of the potential benefits to be gained from such capability.

References

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