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ABSTRACT

A computer program for the sizing of subsonic and supersonic fighter planes was adapted for use in an aerospace engineering course at the University of Texas at Austin. FIGHTER uses classroom notation and separate subroutines for different disciplines to implement the conceptual design process. Input consists of a set of design variables and a set of mission variables. FIGHTER begins by computing the geometry of the aircraft. Next, it is flown (on the computer) through the prescribed mission to compute fuel requirements. After the aircraft has been flown through the entire mission, the design variables, the geometry, and the fuel weight are used to compute a new take-off gross weight. The entire process is repeated until assumed gross weight and computed gross weight differ by a small amount. A formal evaluation of FIGHTER was made by eight instructors of aerospace technology at other universities who used the program. (CH)

PROGRAM FIGHTER:

AN EVALUATION

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by

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Abstract

A computer program for the sizing of subsonic and supersonic fighters has been adapted for use in an aerospace engineering design course. Following a description of the program, an evaluation of its use in the university is presented. It is concluded that computer programs for the conceptual design of aerospace vehicles can play a very important part in design education. First, they give students an overview of the conceptual design process, and second, they illustrate the capabilities of computers in design. The latter is becoming more important as time goes on because industry is moving in this direction.

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Ft. Collins, Colorado 80521

1. Introduction

The aerospace engineering design course at The University of Texas at Austin consists of two hours of lecture and two hours of lab. In the past, the lab period has been used to carry out the conceptual design phase of one or more aircraft using the principles discussed in the lectures. Also, the general procedure was to divide the students into five-man groups, and let each group design an aircraft of their choice. Each member of the group was made responsible for the computations associated with a particular discipline - aerodynamics, propulsion, performance, etc. Almost all computations were done by hand with the slide rule.

While this is an acceptable format in industry, it presents some problem in a university environment. It is difficult to force all students to work at the same pace, and in a team effort, the work of one depends of the results of another. Each student learns a considerable amount about his assigned discipline but very little about the others. The hand computations were involved and time-consuming. Often errors go undiscovered until it is too late in the session to go back and correct them. Also, the time required to carry out one design iteration is normally so great that it is not possible to consider any parametric or trade studies. More often than not, it is difficult to get current design information such as data, procedures, etc. For example, engine data is usually requested from the manufacturer and does not always arrive when needed. Finally, as far as this list is concerned, it · difficult to evaluate the efforts of individual students and not always fair to give all members of a group the same grade.

About three years ago, the authors got the "brilliant" idea that a computerized conceptual design system could solve all of the problems. Each student could work at his own pace and be fairly graded; each student would learn something about design in all disciplines; hand computations would be kept to a minimum so that errors would be eliminated and trades could be analyzed; and current design information would be contained in the system. Also contained in the "brilliant" idea was that the system would be able to design all types of airplanes in all speed regimes. While the theory was sound, the time, effort and money required to create such a system was prohibitive.

As work began on the system and as the magnitude of the project rapidly became apparent, the existence of a number of small airplane sizing programs became known. The purpose of this paper is to discuss one of these programs, FIGHTER, and to present an evaluation of its use in the university. The work on program FIGHTER and its evaluation have been supported by Project C-BE, whose initials stand for Computer-Based Science and Engineering Education. This project has been sponsored by a National Science Foundation grant to the University of Texas at Austin.

2. General Description of FIGHTER

The computer program FIGHTER is essentially the simplest program which can be written for sizing subsonic and supersonic fighters. The program originated at Grumman (Ref. 1), but a modified version was obtained from the Air Force Flight Dynamics Lab. Since then, the program has been rewritten using a standard classroom notation and making each discipline a separate subroutine. The sequence of computations in FIGHTER as it now stands is shown in Figure 1.

The input to FIGHTER consists of a set of design variables and a set of mission variables. The design variables include the ultimate load factor, the maximum equivalent airspeed, the maximum Mach number, store weight, engine type, various fixed weights, the wing loading, the thrust-to-weight ratio, and initial estimates for the take-off gross weight and the maximum sea level static thrust. In order to carry out sensitivity studies, provisions have been made to prescribe any or all of the parameters defining the wing. The mission variables include the sequence of mission segments, and the altitude, Mach number, and load factor of each. Possible mission segments include take-off, climb, cruise, combat (turns, acceleration, and specific excess power), and landing.

FIGHTER begins by computing the geometry of the aircraft using statistical correlations for the independent geometric parameters and definitions for the remaining variables. Examples of the former are shown in Figures 2 and 3. Next, the aircraft is flown through the prescribed mission to compute the amount of fuel required. Climb, cruise and turns are assumed to be quasi-steady so that point performance is valid. On the other hand, take-off, acceleration, and landing are nonsteady. To compute nonsteady performance and overall performance (i.e., time-to-climb), average quantitites are employed. In almost every mission segment, there is an inequality constraint which must be satisfied. For example, in a turn, the maximum thrust must be greater than or equal to the drag. If an inequality constraint is not satisfied, the maximum sea level static thrust is increased by 2%, and the performance calculations are restarted. In each segment, the aerodynamic and propulsive characteristics of the aircraft are obtained from the respective subroutines.

With regard to aerodynamic characteristics, the drag polar is assumed to be parabolic. The zero-lift drag is composed of skin-friction drag and wave drag. The former is computed by the equivalent parasite area method with appropriate interference and compressibility factors, and the latter is obtained from a statistical correlation. The induced drag is computed in the standard way with a statistical formula for Oswald's efficiency factor. Typical Mach number distributions for these quantities are shown in Figures 4 and 5.

The propulsion characteristics are obtained by assuming a typical engine whose maximum sea level static thrust can be varied. Examples of thrust and specific fuel consumption are shown in Figures 6 and 7.

After the aircraft has been flown through the entire mission, the design variables, the geometry, and the fuel weight are used to compute a new take-off gross weight from a set of statistical weights formulas. Then, with the new gross weight and maximum sea level thrust, the whole process is repeated. This procedure is continued until the assumed gross weight and the computed gross weight differ by a small amount. The resulting aircraft is then considered to be sized for the mission.

3. Example Problem

The statistical formulas in FIGHTER are based on existing aircraft through 1969. Hence, a good test of FIGHTER would be to apply it to the sizing of an aircraft which did not exist at that time. The sizing of an aircraft for the air-superiority mission of the F-16 provides such an example. The design specifications and the mission specifications are shown in Figures 7 and 8. A comparison of the results from FIGHTER and the published results for the F-16 are shown in Figure 9. The fact that FIGHTER has done such a good job is most likely due to the values chosen for the wing loading (75 lb/ft^2) and the thrust-to-weight ratio (1.2), which are actual values for the F-16. The discrepancy in fuel weight is quite large and needs some investigation.

Incidentally, FIGHTER uses approximately 10 sec of CDC 6600 computer time to carry out the sizing of an aircraft (about 20 iterations).

4. Intended Use of FIGHTER

Regardless of the goals established for FIGHTER in the Introduction, it is essential that students using the program become as familiar with the program as if they had written it themselves. Hence, as the instructor lectures on the prediction methods used in FIGHTER, students are expected to carry out one iteration by hand. Through proper selection of the take-off gross weight and the maximum sea level static thrust, an iteration can be set up in which the engine size is not increased during any mission segment, thereby minimizing the hand computations. Upon completion of the hand computation, the student is allowed to complete the iteration process with FIGHTER or to carry out the sizing of an aircraft to his own specifications. At this point, parameter studies are conducted with the goal of minimizing the take-off gross weight which is equivalent to minimizing the airframe cost. Finally, the student is required to prepare a report containing the hand computations, the final iterations, the parameter studies, a discussion of the design and performance of the final configuration, and a three-view drawing of the airplane. All of this can be accomplished in approximately three weeks of class time plus approximately three more weeks for the student to complete his work. The remaining course time could be devoted to the conceptual design of a timely aircraft or to a more detailed design study of the aircraft just sized.

5. Evaluation of FIGHTER

An attempt has been made to evaluate the use of program FIGHTER in an aerospace engineering design class, both at UT Austin and at other universities. Local evaluation has been the easiest to perform and is discussed first.

Program FIGHTER has been used at UT Austin the past three semesters. Since neither of the authors is the instructor of the design course, the evaluation should not be biased. The course is composed of two one-hour lectures per week and one two-hour lab. Lecture time is spent discussing general aspects of design, while the lab is based on two computer programs, one of which is FIGHTER. The instructor, Dr. Westkaemper, is satisfied with the results achieved using FIGHTER for several reasons. Prior to the use of FIGHTER, the course was conducted in a team fashion, and each student learned in-depth about his particular discipline. With FIGHTER, each student learns something about each discipline, which is better from an educational point of view since the students do not know where they will be working or in which discipline. Second, it introduces the students to a collection of empirical and/or statistical relations which had not been used previously and which had not been discussed in other courses. Finally, it shows how a collection of some really crude formulas can be put together to obtain a reasonably accurate sizing of an aircraft.

The outside evaluation of FIGHTER has been difficult to achieve. Invitations to participate in the evaluation were sent to the fifty-three universities whose chairmen belong to the Aerospace Department Chairman's Association. These instructors were asked to return the form even if their response was negative since this would give us on idea about what was happening in aerospace design around the country. Of the twenty-four replies, fourteen agreed to use the materials and help us carry out the evaluation. Six of the ten who said they could not help were already committed to specific projects such as the Bendix design competition, another aircraft, or another computer program. In particular, Professor Corning (University of Maryland) is writing a synthesis program along the lines of his text on subsonic and supersonic airplane design. Also, Professor Stillwell (University of Illinois) is committed to the support of the aerospace engineering part of PLATO, which is a large scale computer-based education system and which contains a part on airplane design. The remaining four responses were negative because two of the schools did not have an aerospace vehicle design course, because the instructor did not want to constrain his class to a fighter design, and because the instructor already used this format, but the students wrote their own programs.

This brings us to the fourteen instructors who agreed to help evaluate FIGHTER. They were sent a copy of the computer program in card form, permission to duplicate the documentation on FIGHTER for their students, and an evaluation form which was to be returned on the completion of the evaluation -- supposedly by the end of the Spring session. By the time this paper was written, four instructors had not yet responded. Two responded that they had been unable to use the program in class because of participation in the Bendix design competition and because modification of the program had not been completed in time for the course. The remaining eight evaluators got the program working on their computers; three of them used it for individual student projects, and five used it as part of their design classes. Following some general evaluation comments, more will be said about the individual efforts.

In spite of the serious attempt made to create an easily transferable product, a few problems did occur. The problems centered on hardware differences and included different output characteristics different alphanumeric field lengths and different keypunch formats. No one, however, experienced difficulty getting FIGHTER to run on their computers. In all, CDC, IBM and UNIVAC computers were involved. Finally, it should be mentioned that all nine of the instructors who worked with FIGHTER have previously used computers for one reason or another.

In the formal evaluation of FIGHTER, the technical content, the clarity, and the effectiveness of the materials were rated excellent. Nearly all of the instructors who used the program said that they will use it again, mainly as a graded homework assignment. Criticisms of the material were that the definitions of the input data were not completely clear and that flow charts of each part of the program were lacking.

In an attempt to give credit to those who worked with FIGHTER, a summary of the individual efforts if presented here. Professors Arthur Bruce (Louisiana Tech), Esam Nassar (IIT), and Ricardo Zapata (University of Virginia) used the FIGHTER for individual student projects. Professor Bruce has also indicated that he will modify and/or create discipline subroutines to convert FIGHTER to a light aircraft synthesis program. Professors George Bennett (Mississippi State) and Julian Doughty (University of Alabama) used the program as homework assignments. Professor Barnes McCormick (Penn State) had one-third of his design class convert FIGHTER to a program for the synthesis of a fan-jet commuter transport.

Professors P. A. Lord (Northrop Institute) and Donald Ritchie (Embry-Riddle) used Fighter as originally intended to come up with a "ball-park" aircraft which is then used as a basis for preliminary design considerations. In this connection, Professor Lord used the "ball-park" airplane to conduct a CCV design project. Professor Ritchie has had the program rewritten in BASIC so that it can be used on their HP 2000 mini-computer from terminals in the airplane design lab. Furthermore, to aid the student during input, the program has been written in a conversational mode.

Finally, Maj. Thomas Pilsch (Air Force Academy) pursued the use of FIGHTER in a more conventional manner, that is, design around a given engine. The engine was based on advanced technology and was obtained from an engine synthesis program. In his evaluation, he sent a copy of the RFP and engine data used at the Academy. The data contained in the RFP has helped us clarify some of the input data such as avionics and miscellaneous armament weights.

6. Conclusions

As a result of the internal and external evaluation, it is felt that FIGHTER serves a useful purpose in an aerospace engineering design course. In effect, FIGHTER brings the conceptual design process as performed in industry to the university and allows the students to get an overview of the conceptual design process in a way consistent with the direction in which industry is moving-- toward computerized design.

It is not necessary to devote the entire course to computerized design, nor is it necessary to use FIGHTER as it stands. A conceptual design system such as FIGHTER can be understood in a few weeks, and the rest of the session can be devoted to preliminary design considerations of the aircraft sized by the system. Also, once the structure of one program such as FIGHTER has been understood, it is fairly easy because of its modular construction, to convert the program to other types of aircraft.

References

1. Gersch, A., and D. Reichel, CISE, Computerized Initial Sizing Estimate, Grumman Aircraft Corporation, Report No. PDR-AI-70-1, January, 1970.

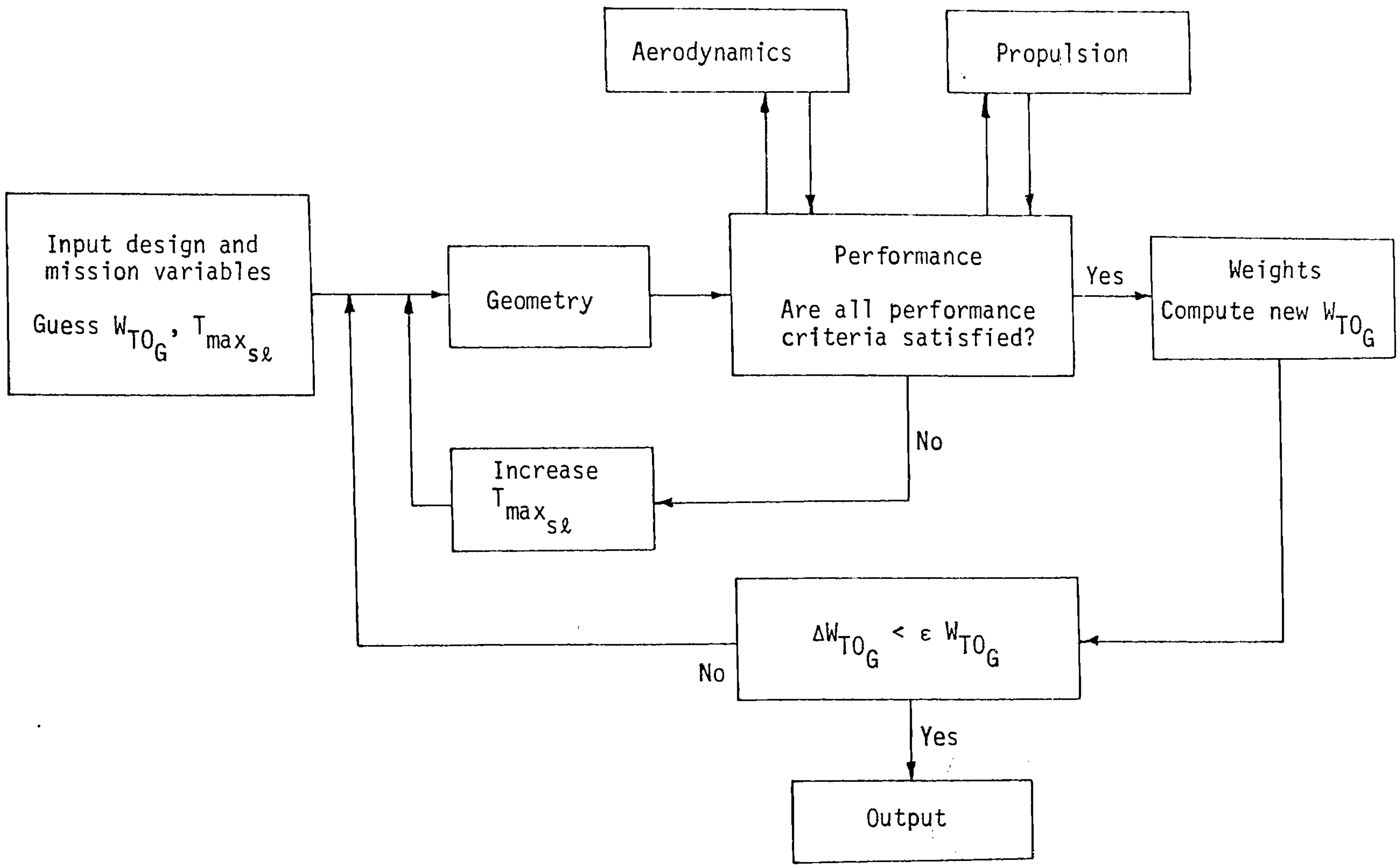

Fig. 1. Sequence of Computations.

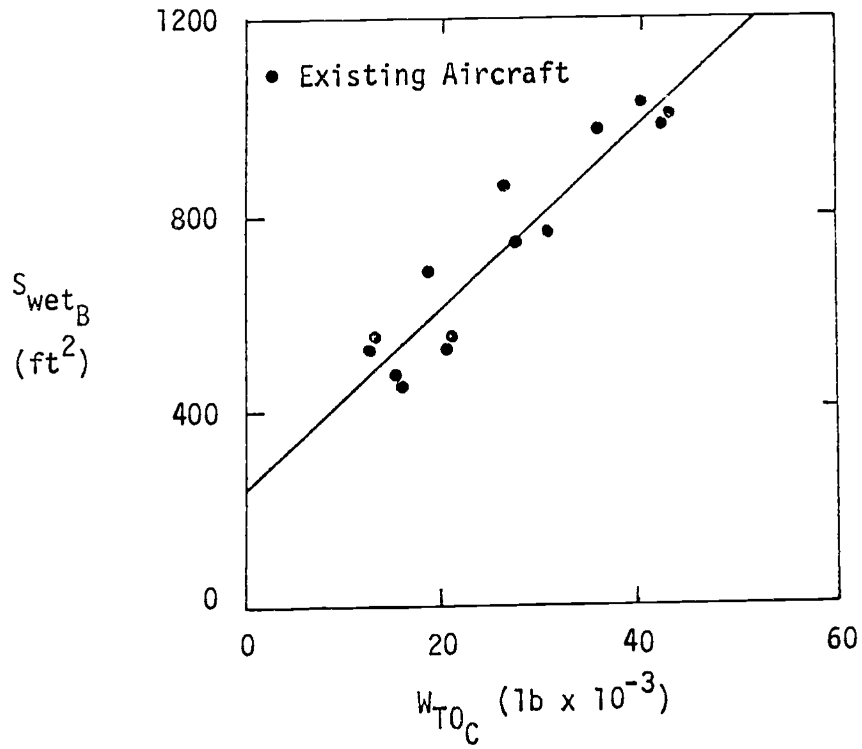

Fig. 2. Statistical Relation for Body Wetted Area.

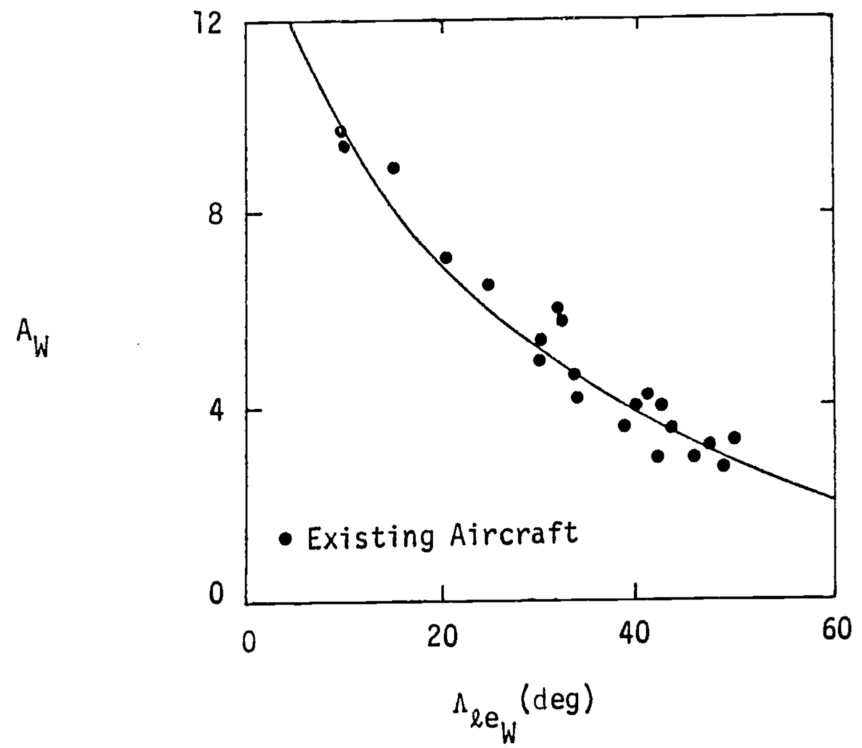

Fig. 3. Statistical Relation for Wing Aspect Ratio.

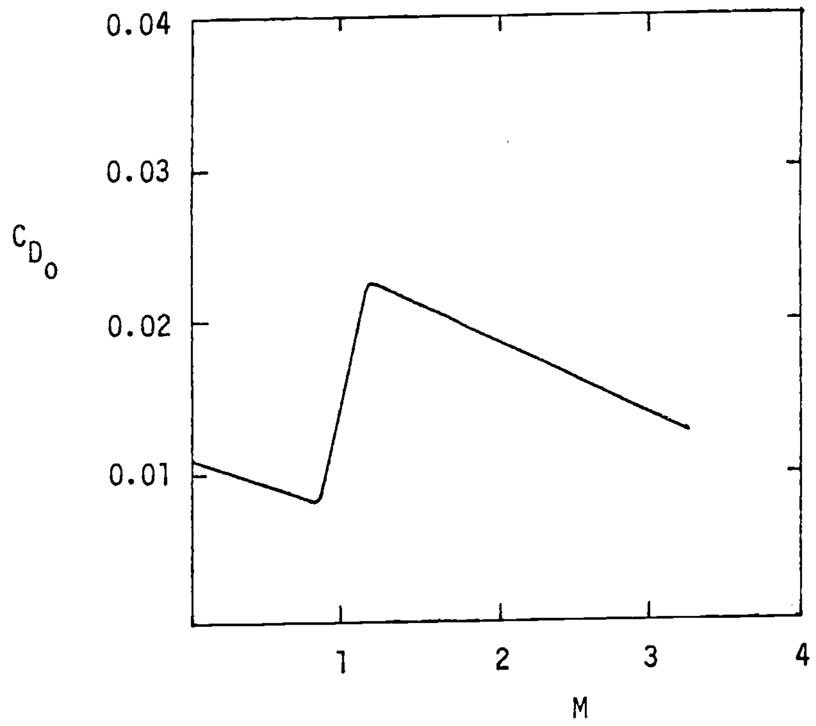

Fig. 4 Zero-Lift Drag Coefficient.

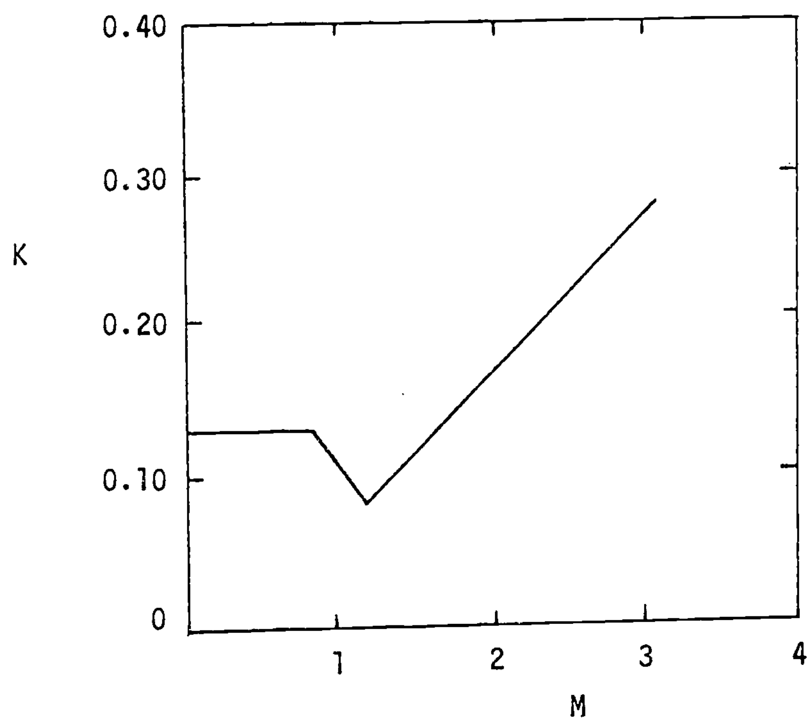

Fig. 5 Induced Drag Factor.

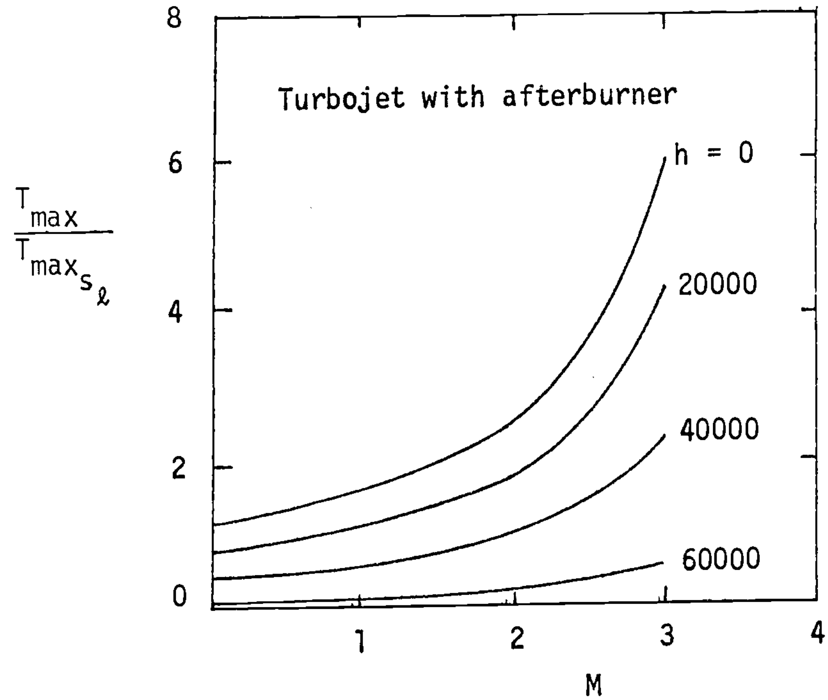

Fig. 6 Thrust.

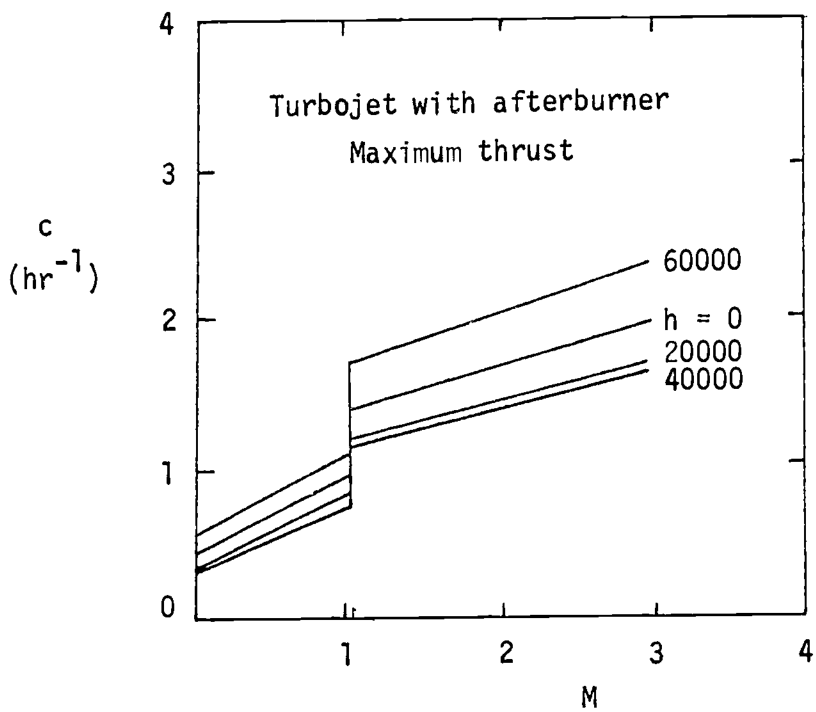

Fig. 7 Specific Fuel Consumption.

Crew: 1

Maximum Mach number: 2.0

Weapons: Two AIM-9 Sidewinder air-to-air missiles
One 20 mm cannon and 500 rounds of ammunition

Engine: Turbofan with afterburner
Engine thrust-to-weight ratio: 8.0

Structure: Conventional construction (no composites)
Limit load factor: 9 g's
Maximum equivalent airspeed: 730 kts

Take-off wing loading: 75 lb/ft^2

Take-off thrust-to-weight ratio: 1.2

Fig. 8 Design Specifications

Warm-up and take-off: Sea level

Climb: Military power, M = 0.9

Cruise: Combat radius 250 nm, M = 0.9
36,000 ft outbound, 44,000 ft inbound

Combat: Four 360° turns: M = 0.9, 30,000 ft, 6.5 g's
Three 360° turns: M = 1.2, 30,000 ft, 6.5 g's
Acceleration: M = 0.9 to 1.6, 30,000 ft

Loiter: 20 min. at sea level

Landing: Sea level

Fuel reserves: 5%

Fig. 9 Mission Specifications

Parameter	FIGHTER	F-16
Body length	43 ft	47 ft
Wing thickness ratio	.05	.04
Wing planform area	280 ft^2	280 ft^2
Wing sweep	44 deg	40 deg
Wing aspect ratio	3.5	3.0
Wing span	31 ft	30 ft
Take-off gross weight	20,900 lb	21,000 lb
Fuel weight	4,700 lb	6,700 lb

Fig. 10 Comparison of Results

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Strucrural Analysis—Dr. Eric Becker

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