Aircraft Design Augmented by a Man-Computer Graphic System

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A status report is presented on one facet of a continuing research and development program at the Lockheed Georgia Research Laboratory in the application of man-computer graphic systems to the design and manufacture of aircraft. The program described is one of the initial steps contributing to the eventual evolution of a computercentric engineering/manufacturing/management system. It is being developed as a prototype covering the aircraft preliminary design and performance estimation process. This prototype will enable a creative design engineer to evolve and refine an aircraft configuration rapidly, by graphically and numerically describing aircraft components to a computer, using interactive, on-line, graphic display devices and unique, generalized graphic programs, by directing the computer through analyses of the configuration or components, and by reviewing directly on the computer-driven display the results of the analysis for approval or modification. A time compression of the preliminary design process of perhaps 10-to-1 is one of the goals of this system. The system is discussed in general, and the graphic and analytical routines are described in some detail. Photographs show the graphic terminals being used in the execution of key steps in the preliminary design process.

Introduction

SINCE early 1964, Systems Sciences personnel at the Lockheed-Georgia Research Laboratory have been conducting research and development in the field of man-computer synergetic systems. A synergistic relationship between man and the computer is becoming feasible through the development of techniques that allow a freely flowing interchange of information. Such a "real-time conversation" is a prerequisite to merging the attributes of the digital computer (speed, memory capacity, accuracy, and reliability) with those of the human (intuition, invention, curiosity, cognition, and decision-making) into a truly effective creative team.

Lockheed-Georgia, typical of companies in the aerospace industry, depends on creativity (principally in the design process) for success. One of the major areas of emphasis in research in man-computer systems, therefore, has been in the field of computer-aided design (CAD). This work is directed toward significant improvements in methods of employing computers to solve the large class of problems involving complex geometric figures or system topology that are characteristic of the design process. These problems conventionally use graphics as the method of analysis, and a traditional limitation of computers has been the impossibility of communicating with them graphically. Methods have now been developed by which it is possible to use digital techniques to make graphic problem statements to the computer and to have the computer understand and correctly interpret the meaning of the picture. Much of the pioneering in this concept was done at the Massachusetts Institute of Technology, as discussed in Refs. 1–4.

The CAD concept is based on developments that permit light-sensing devices and cathode-ray tubes, driven by digital commands, to be attached to computers in such a manner that their interaction can be programmed; and further, that the resulting interactive programs will produce visual displays appearing to the human user as conventional drawing modes with which he can work naturally. Investigations of these interactive graphics systems make it apparent that the newly emerging concepts will be as revolutionary to the application of computers to the design of aircraft during the next decade as the computer itself has been during the past decade. Systems under development using these devices are categorized as man-computer graphic (MCG) systems.

The aircraft design process is highly reiterative, especially so in the preliminary design (PD) phases. In PD, these iterations occur between geometric definitions of the vehicle and analyses of the influence of the geometry on the performance of the vehicle. Although the analytical procedures are complex, they are, in general, relatively well-established. If these procedures were merged, through interactive programming techniques, to computer-graphic methods of rapidly defining and modifying aircraft geometry, it appears that a time compression of the PD process of perhaps 10-to-1 might be realized. An intensive investigation of the application of MCG techniques to aircraft preliminary design and performance estimation was started at Lockheed-Georgia soon after the man-computer systems research program was established. The status of this investigation is presented in this paper.

MCG in the Aerospace Industry

Initial studies of applications through which MCG techniques appeared potentially profitable to the aerospace industry revealed several specific areas. Included among these are preliminary design and performance analysis, aerodynamic analysis, structural design and analysis, dynamics, electronic circuit design and analysis, information processing, numerical control tape generation, and management systems.

The aircraft preliminary design and performance analysis application was revealed to be particularly attractive because of the basic interdependence between graphics and analysis. The influence of the geometric definition of the aircraft on the analysis conducted to ascertain its performance and, conversely, the influence of the analysis upon the geometry of the

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aircraft are so great that the interaction between the man, the graphic interface, and the analytical capability of the computer are maximized. Capabilities developed to satisfy these requirements would encompass a very broad band of all capabilities essential to MCG systems. Also, the preliminary design process is a true subset of the complete aircraft design process. Essentially every facet of the aircraft design problem is treated, but to much less depth of detail and scope. It appears that the framework of a computer-aided aircraft preliminary design and performance estimating system is essentially the same as that required for a computercentric aircraft engineering system. It further appears that a computercentric engineering system provides the base for a broader system which can tie together the engineering/manufacturing/management functions.

Two primary implications of the potential impact of MCG systems on the total aerospace product development process can be considered. First, MCG systems will provide the techniques necessary to digitize that very large remaining segment of data which, heretofore, has been recorded and communicated only through graphic modes (drawings, sketches, graphs, and plots). Second, computer technology is currently approaching a status in which it is feasible to consider mass data banks adequate in size to store digitally the total volume of data required by a typical aerospace organization.

It is appropriate, then, to consider the long-range influence of MCG systems on the aerospace industry in terms of reconfiguring the organization around a computercentric engineering/manufacturing/management system. A schematic diagram of such a system appears in Fig. 1. This shows the relationship between the total data set (which contains in the data bank all the facts necessary to specify the design, fabrication, and operation of a vehicle system), the library of analytical, evaluation, and processing procedures that established and utilized the data, the interfacing devices by which technical, manufacturing, and management personnel input, access, analyze, and withdraw data, and the central data processor that handles the acquiring, storing, processing, updating, and outputting of the data according to operating instructions.

Consideration of an organization of this type is well beyond the scope of this paper, but some typical examples of the benefits from such a system include decrease in design time spans of up to an order of magnitude in many areas, maintenance of a current data set for use by all organizations, direct management control of all data accepted into the current data set, schedule and budget status information maintained in the data set, an alerting system to all affected organizations when a change in a particular data set is proposed, and control of material and shop orders and parts inventory.

The implications of a computercentric system are stimulating to contemplate, but the evolution of such a system cannot be expected to occur in a short time. The rate of evolution into a practical, reliable, functioning system will depend strongly on the consideration given to the over-all objectives of such a system, as each new computer application is planned and implemented. This over-all objective has been considered in the MCG developments at the Lockheed-Georgia Company. Because the broader concept of computercentric systems was recognized, the preliminary design and performance analysis program has progressed under the general title of computer-aided aircraft design (CAAD).

CAAD Program

The objective established for the CAAD program is to provide a system that will enable a creative designer to rapidly evolve and refine an aircraft design by graphically and numerically describing aircraft configurations or components directly to a computer, specifying directly the mission the aircraft is to perform, directing the computer in an analysis of the aircraft design and performance, and reviewing directly the results for approval or modification. A specification was prepared to guide the development of the CAAD system, and programming started in 1966. The achievement of the program objective is being realized through research and development in four MCG areas, interactive graphic controls provided by a graphic time-sharing system (GTSS), geometric definition programs that permit real-time development of aircraft component geometry, data handling programs that store and retrieve reference and computed data as generated or requested, and analytical programs that compute appropriate information about the aircraft geometry, subsystems, aerodynamic characteristics, or performance.

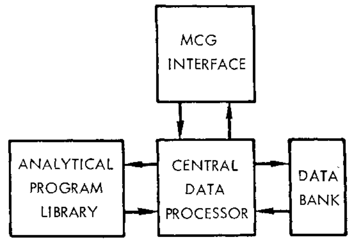

Fig. 1 Schematic of computercentric engineering / manufacturing/management system.

Graphic Time-Sharing System

When the decision was made to develop a computer-aided aircraft design capability, no general operating system was available by which graphic communication could be conducted with a computer under time-sharing conditions. Such a system is a prerequisite to practical MCG applications. Based on knowledge and experience gained from operating a dedicated computer graphic system installed in the Lockheed-Georgia Research Laboratory in 1964 (described in Ref. 5) and justified by adequate requirements for a large-scale production system, specifications for a multiple-console, time-sharing system were established. This system, the GTSS, is described in detail in Ref. 6. It is designed for a CDC 3300 computer system with Digigraphic 270 graphic consoles.

The CAAD program is designed to operate under the GTSS. All external control of CAAD operations is through "light pen picks" of "light buttons" on the CRT. These light buttons are computer-generated displays in the form of messages or key words. When picked, it causes a computer action which can be analyzed by the program to determine the next subroutine(s) to be executed. The program is arranged such that only appropriate and relevant buttons are displayed at any time. After a pick is made, all buttons no longer meaningful to the selected program branch are removed from the display. A new button array can be displayed which provides a new set of alternative branches within the program.

A button array is referred to as a "menu." A menu will present to the operator a list from which to select the next desired step from among a number of steps which could be made. A high-level menu presented to the operator upon initiating the CAAD system provides light buttons which call geometry routines, display-format controls, configuration or figure lists, library interrogations, analytical routines, or data output requests. A pick of one of these buttons will direct the program to the entry point of one of the major CAAD subprograms.

Subprograms Defining Geometry

One of the most challenging problems encountered by the CAAD program was the development of methods for establishing airframe geometry which are compatible with MCG techniques and which produce complete and precise envelope definitions. Exploratory graphic programs developed on the dedicated computer-graphic system provided much of the guidance to the formulation of the selected techniques.

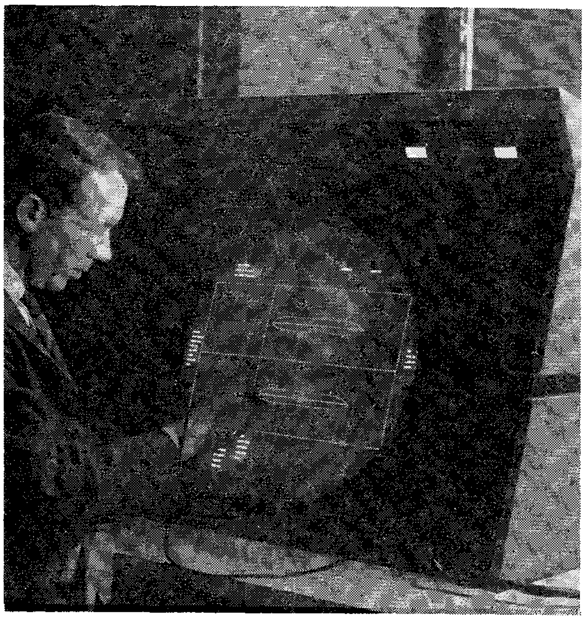

Fig. 2 Operator initiating fuselage design using surface molding subprogram.

Three geometric subprograms appear to provide the capability to define the surface envelopes and geometric constraints necessary to describe essentially all aerospace vehicle components. These are termed surface molding, ruled surfaces, and 3-D drafting. Each figure generated by one of these subprograms is defined relative to its own local reference axes, which are defined, in turn, relative to a set of basic reference axes in a computer-defined universe. The spatial location of a figure local axis system relative to the basic axis system is in terms of the displacement coordinates of the local origin and the angular orientation about each local axis relative to the null, or parallel, axis position.

Within the universe is a "viewbox," which can be freely translated, rotated, reproportioned, and scaled. The viewbox provides, through the MCG interface, the conventional three views of a segment of the universe. Figure geometry and location are defined in full-scale units in the data structure. Since the scale at which the figures are presented on the display is defined by the scale of the viewbox, the conversions from the "real world" definition of geometry to the display coordinate system are through viewbox transformations.

Surface Definition

The development of the surface envelope of the aircraft is fundamental to the success of the CAAD system. The designer should be able to develop the surface envelope in a reasonably short time and should not be burdened with the mathematical details of the surface he is creating. For geometric and aerodynamic information to be calculated in real time, a mathematical description of the surface must be maintained throughout the design process; consequently, it is vital that the mathematical model be compact. The input information necessary to develop the desired surface should be kept to an absolute minimum and be directly associated with the meaningful qualities of the surface. For example, if the designer wishes to raise the aft portion of a fuselage slightly, changing one or two pieces of information which establish the height of the aft fuselage should effect the change, and the new surface should be generated automatically. A particularly important consideration in developing a surface package is to provide a system that will normally produce smooth, fair surfaces suitable for a manufacturing description. Extra effort on the part of the designer should be required to induce waves or ripples in the surface if they are indeed required.

Many well-established techniques are used throughout industry for defining surfaces. Numerical loft methods have been successfully used for several years, and one new parametric surface "patch" method developed at the Massachusetts Institute of Technology (MIT) has aroused considerable interest. All of these methods were considered, but were found to have limitations.

Surface Molding

A concerted effort to find means of suitably describing three-dimensional surface bound shapes led to the development of a new concept in the mathematical description of free-formed surfaces. Experimental programs were developed which, although of limited scope, served to demonstrate the soundness of the approach and formed the basis for the production surface-molding subprogram for the CAAD system. This system allows fair surfaces to be developed in a matter of minutes with light-pen controls that are natural and smooth to operate. A very small amount of input information is required, and the designer need not know the mathematics involved. This system is discussed in Ref. 7.

Fundamentally, the concept of surface molding, as the name implies, starts with a predefined, basic surface shape which is "molded" to satisfy specific requirements. The basic surface is specified by selecting longitudinal functions to form plan and profile projections of the body. These functions are selected from functions available in the computer and displayed on the scope. Body location parameters and length dimension, specified at the time the figure is defined, can be modified at any time.

One of the major advantages offered by this method of surface definition is economy of computer memory storage. The entire basic surface is represented by one term in an equation. In subsequent operations, additional terms can be added to the basic term to mold the surface to the desired form. Any number of terms can be added to the surface equation to obtain a desired surface, but the flexibility inherent in each term makes it likely that only one or two terms will normally be required.

An ability to calculate geometric information about the surface is of prime importance in both design and manufacturing processes. The mathematical description of the surface as one equation greatly facilitates the calculation of this geometric information. Ease of calculation was a major consideration in the development of the process. The form of the surface equation reduces the task to standard mathematical procedures. The photographs of Figs. 2 and 3 illustrate the development of a single-term surface, two or three minutes work for the designer. In Fig. 2 the initial shape has been presented to the designer. Any one of the longitudinal function contours can be changed with a light pen pick to a menu of other contour types, i.e., sine function, circular arc, hyperellipse, or polynominal. Each longitudinal can be divided into as many curve segments as desired. The mating point of each two adjacent segments is defined as a control point for specifying constraint information to the segment contours. Each control point can be moved inboard as far as the reference axis, outboard as far as desired, and forward or aft until it degenerates the length of one segment to zero. The central reference line can be swept up, down, left, or right, to produce an asymmetric body shape, as seen in Fig. 3.† The location of any control marker can be moved using the light pen to specify the new location information. In addition to molding the basic surface term, local molding is provided by permitting a segment of the basic surface to be selected and new function terms added to the basic equation to be effective over this specified segment.

To mold a local segment of the basic surface, the designer must first indicate a longitudinal region over which the mold-

† Figures 3–12 have been enhanced mechanically for clarity of presentation in this journal.

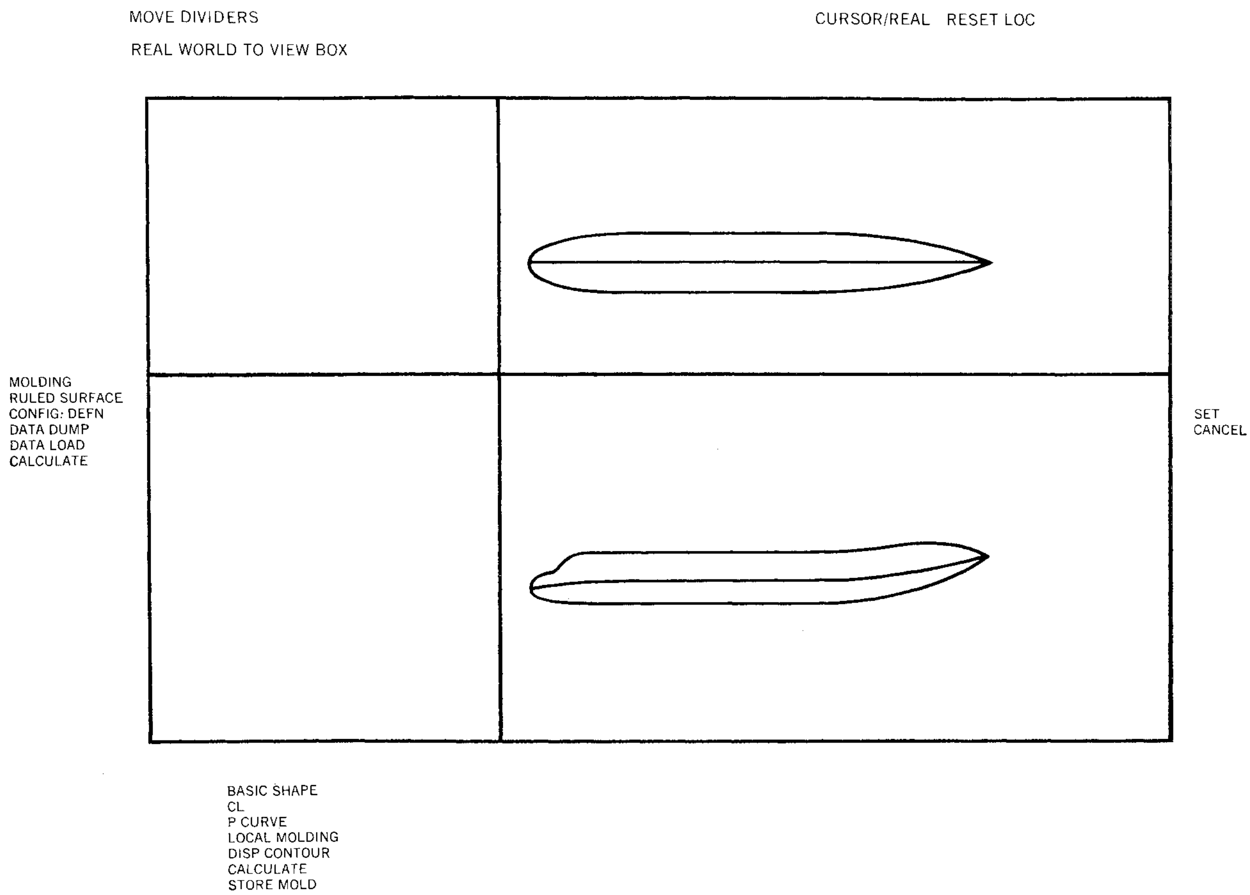

Fig. 3 Basic surface developed for fuselage.

ing is to take place and then select a cross section at some point within this region, as seen in Fig. 4. The surface may then be modified by selecting one of three functions. One changes the selected cross-section shape, another provides control over the weighting of the magnitude of this cross-sectional function between the longitudinal limits, and the third permits control of the angular weighting between the longitudinal limits. Successive local terms may cover the same or overlapping angular regions, or the same or overlapping longitudinal regions. The methods used to specify local molding changes are essentially the same as those used to control the functions of the basic shape. A modified cross section with an additional symmetric local mold term is shown in Fig. 5. Because the mathematical definition of the surface is compact, section cuts can readily be made. Figure 6 shows the result of making several longitudinal and cross-sectional cuts through the body.

From experience gained in the programming and the use of the prototype 3-D molding program, and from developing the production program, it is estimated that the geometry of a typical aircraft fuselage would require no more than 2000 words of storage. Additional routines permit these surface definitions to be converted to other mathematical forms that are compatible with conventional numerical loft definitions. Interfacing of component shape definitions with existing configurations is possible through this capability.

Ruled Surface

The mathematical form of the surface-molding equation is flexible enough to permit the definition of aerodynamic surfaces such as wings, empennage, and pylons. The resulting surface, however, would not necessarily conform to the classic ruled surface definitions conventionally considered for these bodies. In order that the definitions generated in the CAAD system be consistent with conventional methods, a separate ruled surface package, developed specifically for the generation of wings, vertical and horizontal stabilizers, and pylons, forms one of the basic graphic subprograms. In specifying this part of the system, the emphasis is placed on providing a tool that will enable the designer to develop surfaces in terms of meaningful aerodynamic parameters.

The development of ruled surfaces is a two-step process. The designer must first specify planform geometry and then cross-sectional shapes to be located on the planform. A ruled surface lofting performed by the computer completes the surface description.

The program allows the creation of planforms of one, two, or three panels. The designer has the option of choosing the planform area, aspect ratio, sweep angle, etc., and may have the planform and coordinate information computed and displayed, or he may specify the coordinates of the planform and have the calculated parameters displayed. This is a real-time operation at the display so that the designer may adjust the planform as desired. Figure 7 shows the planform of a three-panel wing specified on the display. Also shown in Fig. 7, fuel tank boundaries can be specified on the display by light pen commands. The fuel capacity and fuel centroid of each tank is then computed. These data are stored for later reference by the weight and balance, and mission analysis routines.

Several methods will be provided for specifying the directrices of the ruled surfaces. Currently, for wing, empennage, and pylon design, standard or modified four-digit NACA airfoil sections can be specified. Eventually, additional standard sections or ordinate data may be input to define the wing section. Ultimately a complete three-dimensional wing design program presently being evaluated by wind-tunnel and flight-test programs will be incorporated to permit complete geometric and aerodynamic design of lifting surfaces.

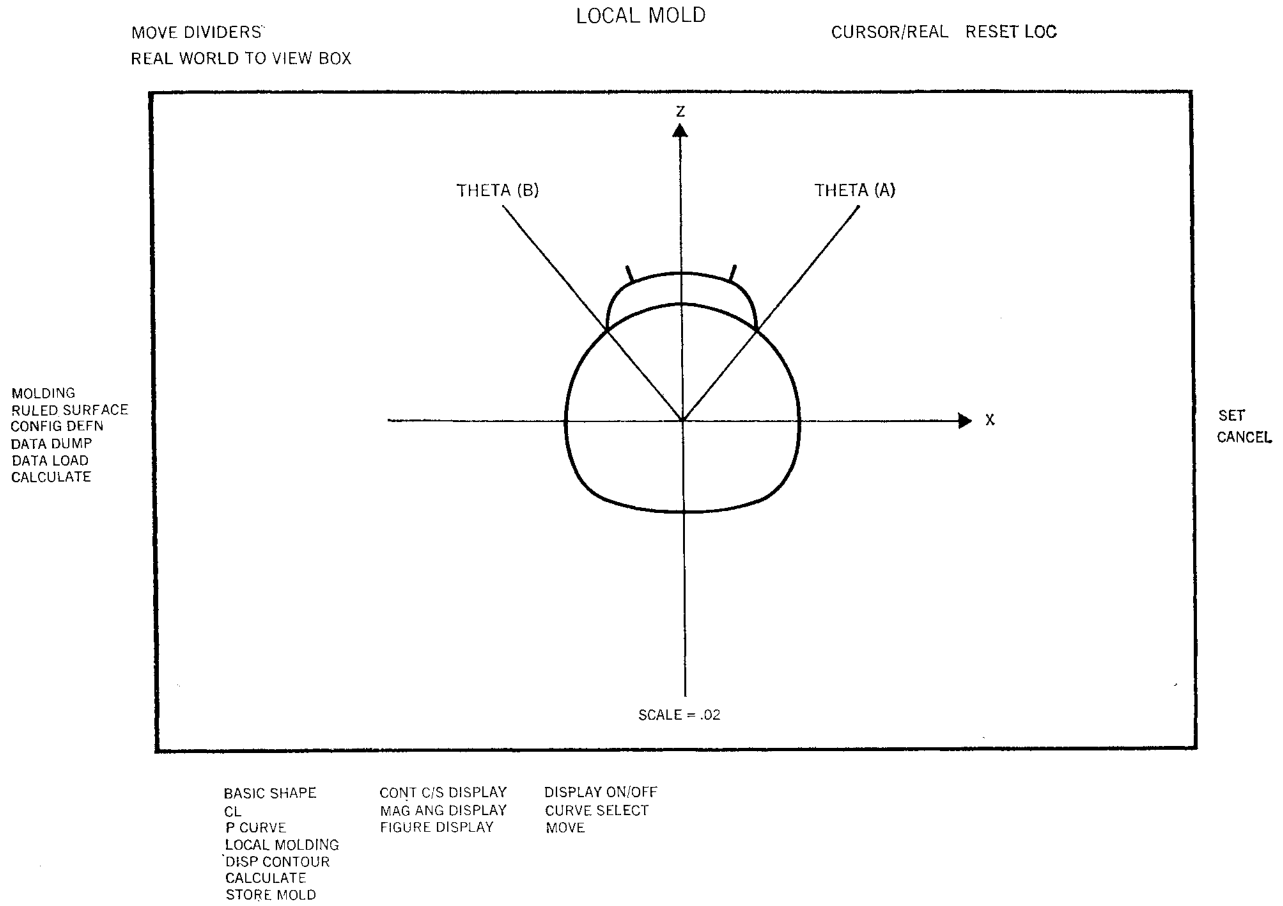

Fig. 4 Local mold term added to upper section of basic surface.

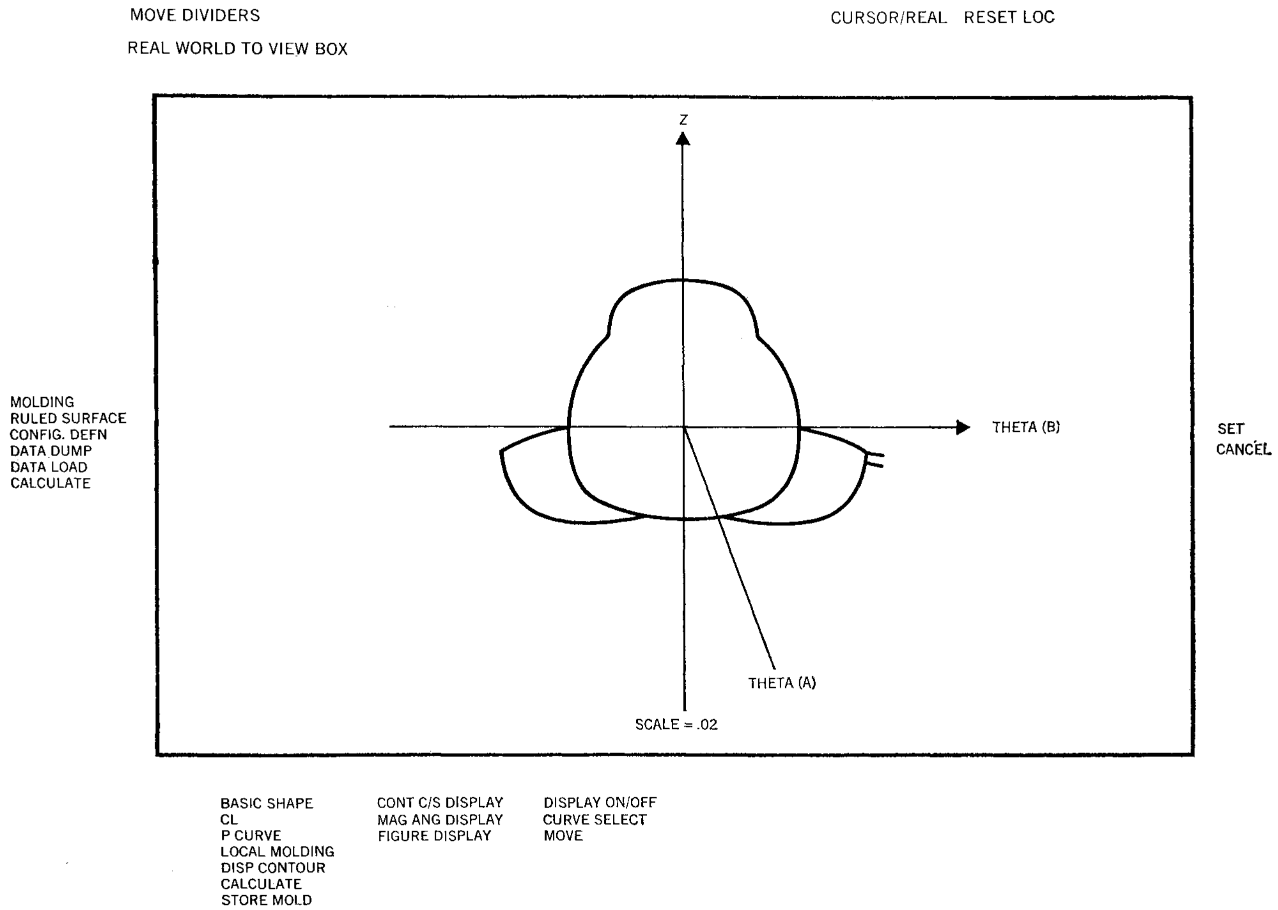

Fig. 5 Final modification of fuselage cross section.

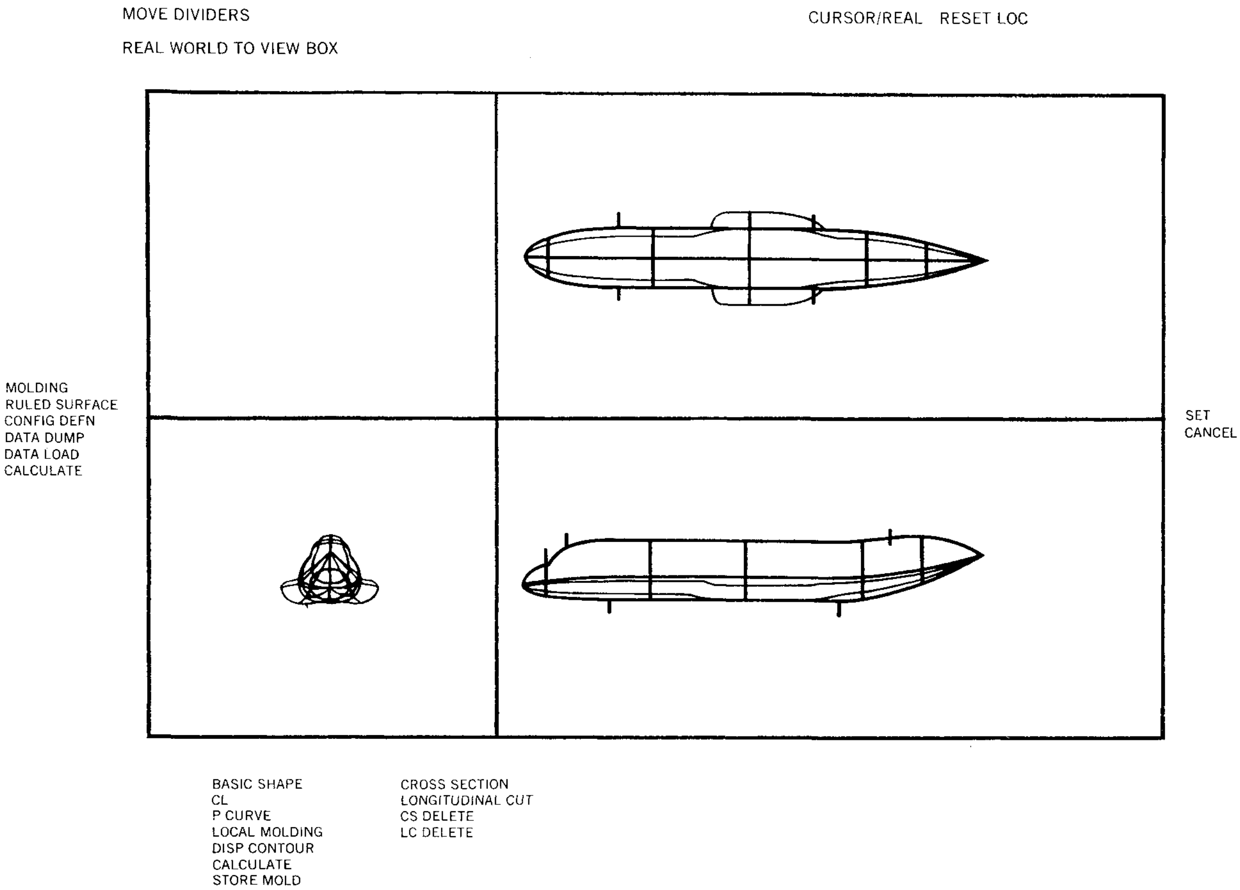

Fig. 6 Cross sections and longitudinal sections of fuselage.

3-D Drafting

The drafting program permits the assimilation of data into a three-dimensional data structure in the computer, from information defined either numerically or graphically in the three orthographic projections of the viewbox on the MCG display. The three-dimensional figures created in this data structure are composed of individually defined discrete elements. The capabilities provided include the three-dimensional definition of points, straight lines, circles, and circular arcs. Surfaces are not defined; consequently, figures generated by these elements consist of "wire frames."

The drafting program will be used principally to establish geometric constraints on the aircraft design. Cargo cubes, passenger compartments, and armament bays are typical of the constraints around which airframes must be configured. The drafting program will also provide the graphic construction capabilities required in general layout design operations, such as parallel lines, perpendicular lines, intersection points, and tangency points.

Experience with both the drafting and molding programs has produced conceptual ideas for integrating certain features of each into a technique for creating surface bounded figures through a discrete-element mode. Expanded capabilities in these areas will come to fruition as the demands of experience with the CAAD system dictate.

Data-Handling System

Fundamentally, the logic of the CAAD system is devised to handle the accumulation of aircraft configuration and performance data produced by the successive processing of many short subprograms and subroutines dynamically selected during the operation of the system. The subprograms fall into one of two general categories, geometric or analytic. The geometric subprograms will be used to create individual geometric figures which, when considered together, define an aircraft configuration. The analytical subprograms use data calculated in the geometric subprograms, and other reference data, to compute the performance of the configuration under specific applied flight conditions.

A large amount of data is generated by the creation and analysis of an aircraft vehicle system. In order to provide an economically acceptable CAAD system to operate on a time-shared computer system, the mass of data generated by the system must be organized and stored in a rapidly accessed data bank external to the main computer memory, such as drums or disks.

The data system developed for CAAD classifies the descriptive data according to that which is pertinent to individual components or specific aircraft configurations. These data are then organized in a storage matrix according to its classifications. This storage matrix consists of configuration-independent (CI) global and local data and configuration-dependent (CD) global and local data. Local data are usable only within one subprogram, but global data are accessible by more than one subprogram.

As each geometric figure is created, it is assigned a name and a reference number. Certain unique labels call subroutines within the subprograms to compute appropriate geometric parameters. Some unique labels are WING, FUSELAGE, PYLON, and H. TAIL, for example. If the label FUSELAGE is assigned to a figure generated using a particular geometric subprogram, it will cause calls to be made to subroutines of this subprogram which compute and store all of the configuration independent global parameters required by any of the analytical routines (such as wetted area, over-all fineness ratio, frontal area, and volume). Many figures may be defined by the same label (WING, for example), but a particular reference number is assigned to only one figure.

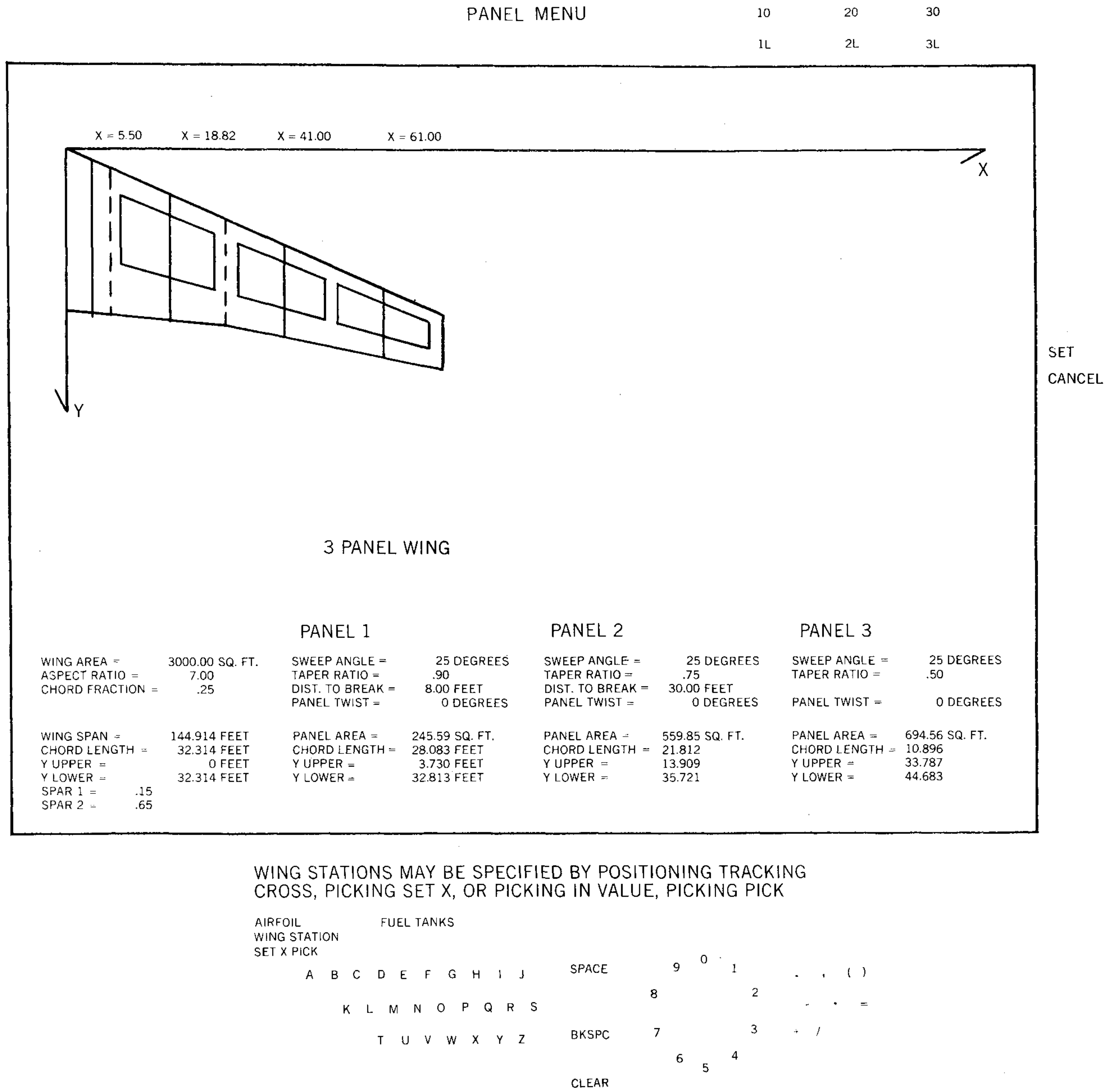

Fig. 7 Wing definition showing control cross-section locations and fuel tanks.

Superimposed over the figure-number system, is a configuration-number system that permits preliminary design studies to be conducted on different aircraft configurations concurrently. A configuration number will string together a series of figure numbers and the associated data lists. A particular figure may be a part of the definition of more than one configuration. A configuration consisting of a fuselage, wing, and vertical and horizontal tail is shown on the display in Fig. 8. The aircraft is displayed at a combination of roll, pitch, and yaw angles, to indicate that it can be oriented as required to aid the designer in developing the desired configuration arrangement. Reorientation is accomplished by simply picking in new values for the orientation angles. A permanent data library contains both the basic reference material required by the engineer, and the analytical routines of the program, such as atmospheric properties, performance parameters for various powerplants, and other required standard reference data.

Analytical Programs

Analytical evaluations can be conducted at many levels. Limited analyses can be conducted on individually defined components without regard to the influence of other configuration components. For example, the relative effects, in terms of weight and drag, of different arrangements of passenger seats on fuselage shape can be examined without considering over-all aircraft performance. A higher level of analysis would include the effect of changes in fuselage length on empennage size, weight, and drag in the previous example.

The greatest value of the CAAD system is its ability to analyze rapidly the effects of variations, such as the fuselage internal arrangement, on the over-all performance of an aircraft configuration on specified missions. This rapid evaluation is possible because of the rapid methods of modifying configuration geometry, the direct link, and the interactive link. The direct link permits the effects of the parameters changed by a geometric change to be immediately recognized and accounted for by the analytical programs. The interactive link permits immediate decisions to be made by the engineer in those situations where the basis for these decisions are so obscure, intuitive, subjective, or complex as to defy a logical simultation.

Conventional batch-processing computer programming techniques require that every decision or branching point be preprogrammed and reduced to a very simple logical status.

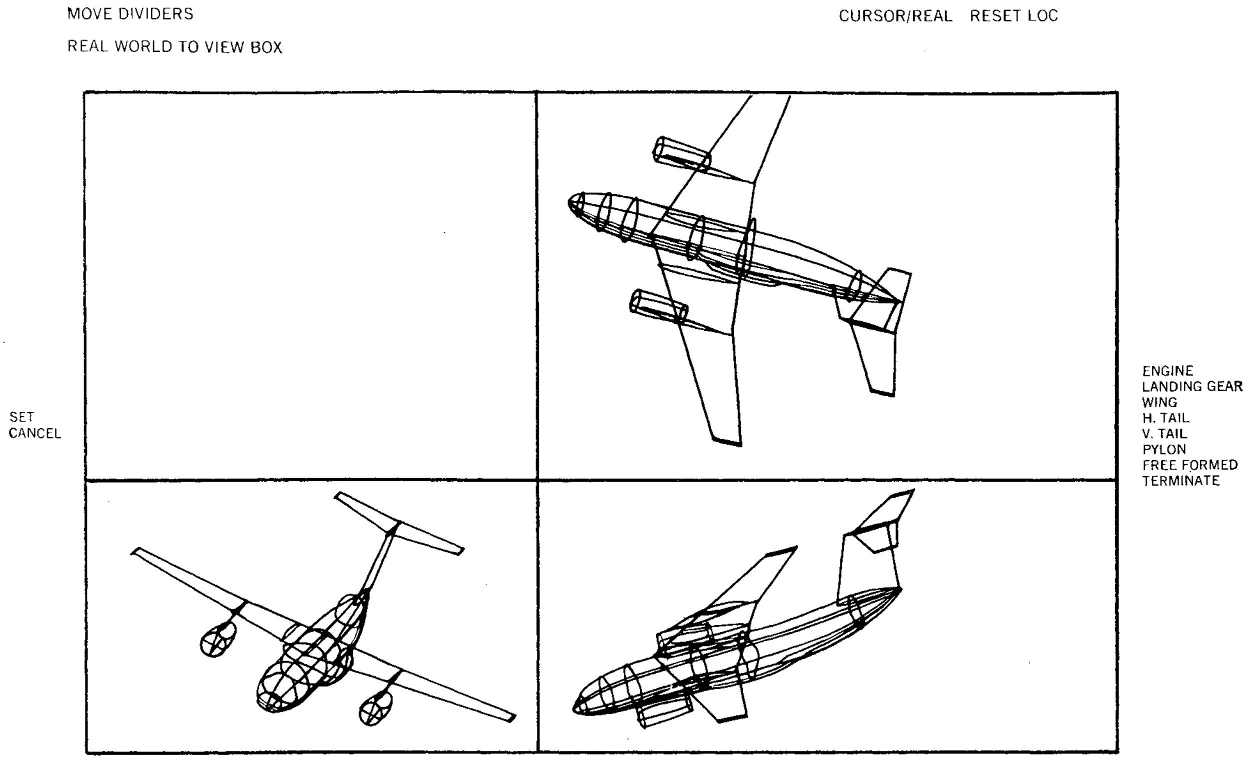

Fig. 8 Aircraft configuration assembled from graphically defined figures displayed at small angles of roll, pitch, and yaw.

If the bases for making a decision are too complex or undefined to allow reduction to a simple logical statement, the program must terminate. The results are printed out for analysis by the engineer who makes the decision and, subsequently, enters new data into another computer program to analyze the problem downstream from the decision point.

In the conversational environment of the CAAD program, it is no longer necessary to terminate the program if decision points are encountered which are beyond the capability to quantify into simple, logical terms. Instead, available options pending the decision can appear on the display as light buttons in the form of written statements and a request for a decision presented. The operator may, after consideration of each choice, make his decision by picking one of the options with the light pen. The light-pen signal provides the cue necessary to initiate processing of the selected analytical subroutine.

The analytical subprograms fall roughly into five categories, weight and balance analysis, landing gear analysis, mission definition and performance analysis, propulsion system analysis, and aerodynamic analysis. These subprograms use data provided by three primary sources, that which is calculated and stored during the generation of each geometric figure, basic reference data obtained from the permanent data library, and independent variables input by the engineer on program request.

The results of each analytical routine are displayed to the engineer prior to proceeding to the next step, if desired. Upon reviewing the data, the design of any component or the input value of a variable can be changed and the analysis repeated.

Weight and Balance Analysis

The analytical procedures incorporated to compute weight and balance are directly derived from well-developed methods currently used by the Lockheed-Georgia Advanced Design Weights Organization. The routines calculate the weight, center-of-gravity location, and moment-of-inertia about the aircraft reference axes of each structural component, each subsystem, the individual tank and total fuel weight, the payload weight, and the integrated sum of the complete aircraft.

If desired, the weight of any component can be specified by the operator, and the weight and balance updated to include the effect of this change. Figure 9 illustrates a typical weight summary presented on the display. The first column of numbers is computed from the parameters defined by the configuration. The second column of figures is an updated

WEIGHT AND BALANCE ANALYSIS

WNLG	1131.8	1140.7	WHYD	1857.4	1857.4
WMLG	8299.8	8365.2	WINST	600.7	600.7
WCONTR	3619.8	3640.0	WHT	3431.6	3450.0
WPP	20842.0	20842.0	WVT	2745.4	2748.9
WNAC	5576.2	5576.2	WAI	2065.4	2082.8
WFURN	4255.4	4288.8	WAC	3040.4	3048.0
WFUS	27890.8	27944.9	WAPU	544.0	546.0
WELEC	3444.3	3457.0	WMISC	1075.0	1075.0
WAV	2529.4	2544.0	WOIL	160.0	160.0
WWING	22435.7	24715.5	WUFUEL	947.5	947.5

OP. WEIGHT EMPTY	116492.2	119030.6
**WCARGO	30000.0	60000.0
ZERO FUEL WEIGHT	146492.2	179030.6
**WFUEL	150000.0	120000.0
GROSS WEIGHT	296492.3	299030.6

FOR NEW UPDATE–PICK	CHANGE
TO REVIEW SELECTED OPTIONS–PICK	REVIEW
FOR BALANCE CALCULATIONS–PICK	BALANCE

Fig. 9 Aircraft weight summary presenting data for two weight conditions.

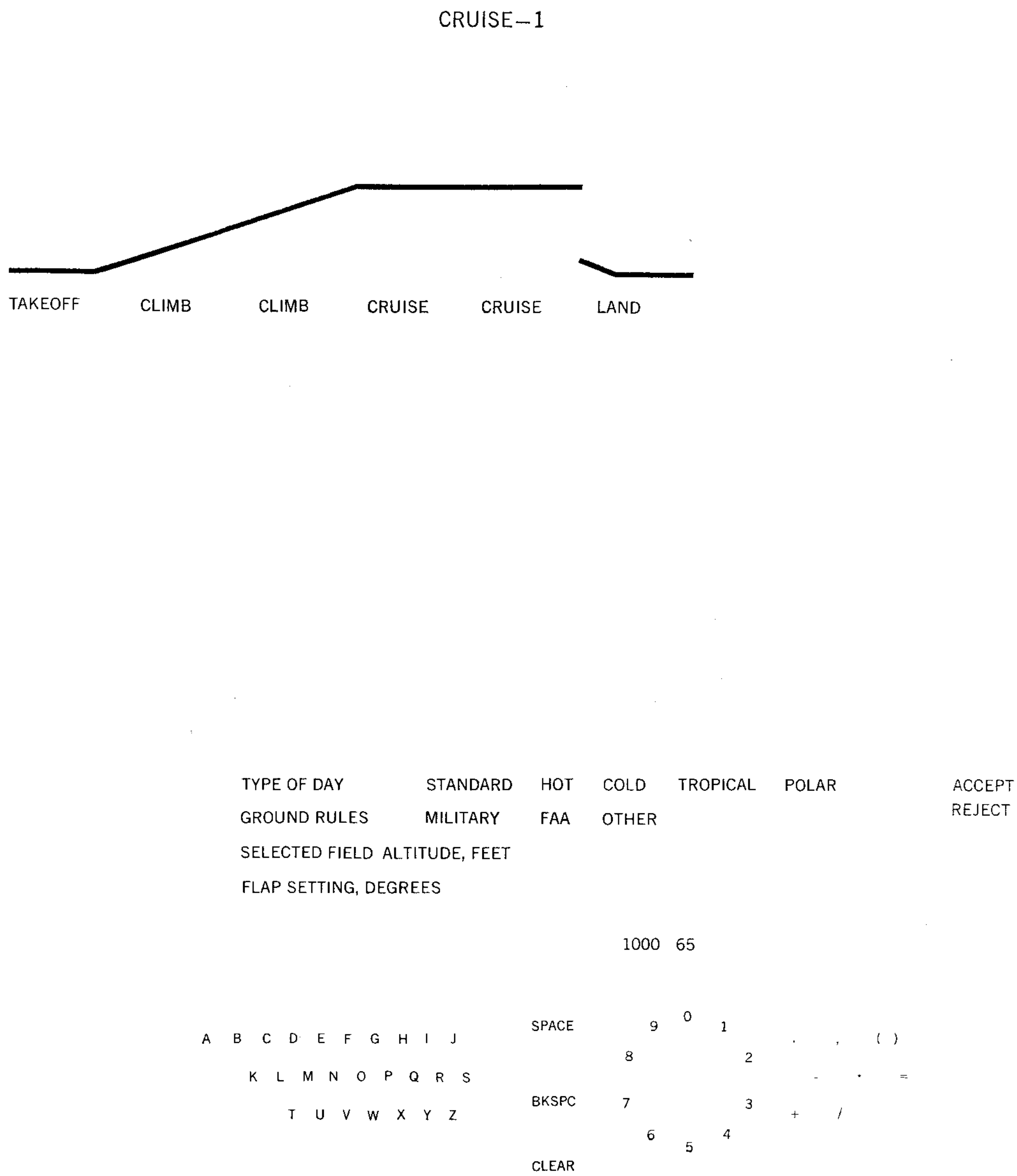

Fig. 10 Mission profile defined via the MCG console.

weight summary in which the weights of those items marked with the double asterisk have been specified by the operator. If out-of-limit, center-of-gravity conditions are found for any weight condition, the design or location of any structural component or subsystem can be modified and the weight and balance procedure reiterated until an acceptable balance is achieved for all weight conditions.

Landing Gear Analysis

A subprogram is being developed to analyze landing gear requirements in terms of basic independent input variables such as flotation and airfield type. From large families of tire contact patterns, those few combinations of tire type, size, arrangement, and spacing which most effectively satisfy an analytical measure of effectiveness are presented to the designer. Using these optimal arrangements, tradeoff studies accounting for the influence of each gear on aircraft performance can be conducted.

Mission Definition and Performance Analysis

The performance of the aircraft will be established by analyzing the configuration against a defined mission profile. A mission profile will be defined by linking together predefined mission phases. The mission phases initially defined include warmup and takeoff, optimum climb, maximum range cruise, maximum endurance loiter, optimum descent, maximum speed dash, hover and VTOL, and conventional landing. It is contemplated that essentially all mission requirements can be satisfied by mission profiles assembled from these basic mission phases.

The assembling of mission phases into a mission profile will be accomplished by successive light pen picks to the phase names displayed as a menu. As each phase is selected, a schematic picture of the mission profile created on the display will be modified to include the added phase. Figure 10 shows the display of a mission profile that includes conventional takeoff, climb, max-range cruise, and landing phases. Basically, the mission-definition subprogram structures the order in which the mission phase analysis subroutines will be executed. An established mission profile can be assigned a unique label (or number) and stored for later recall. When a stored mission profile is to be used, a menu of stored missions can be called to the display and the desired one picked.

There are several analytical options for each phase analysis. Selection of the option to be executed will be made by the engineer with a light-pen pick to an option menu presented as each mission phase is selected. The input to each phase is either the initial aircraft start-of-mission parameters or the output parameter of the previous mission phase. The princi-

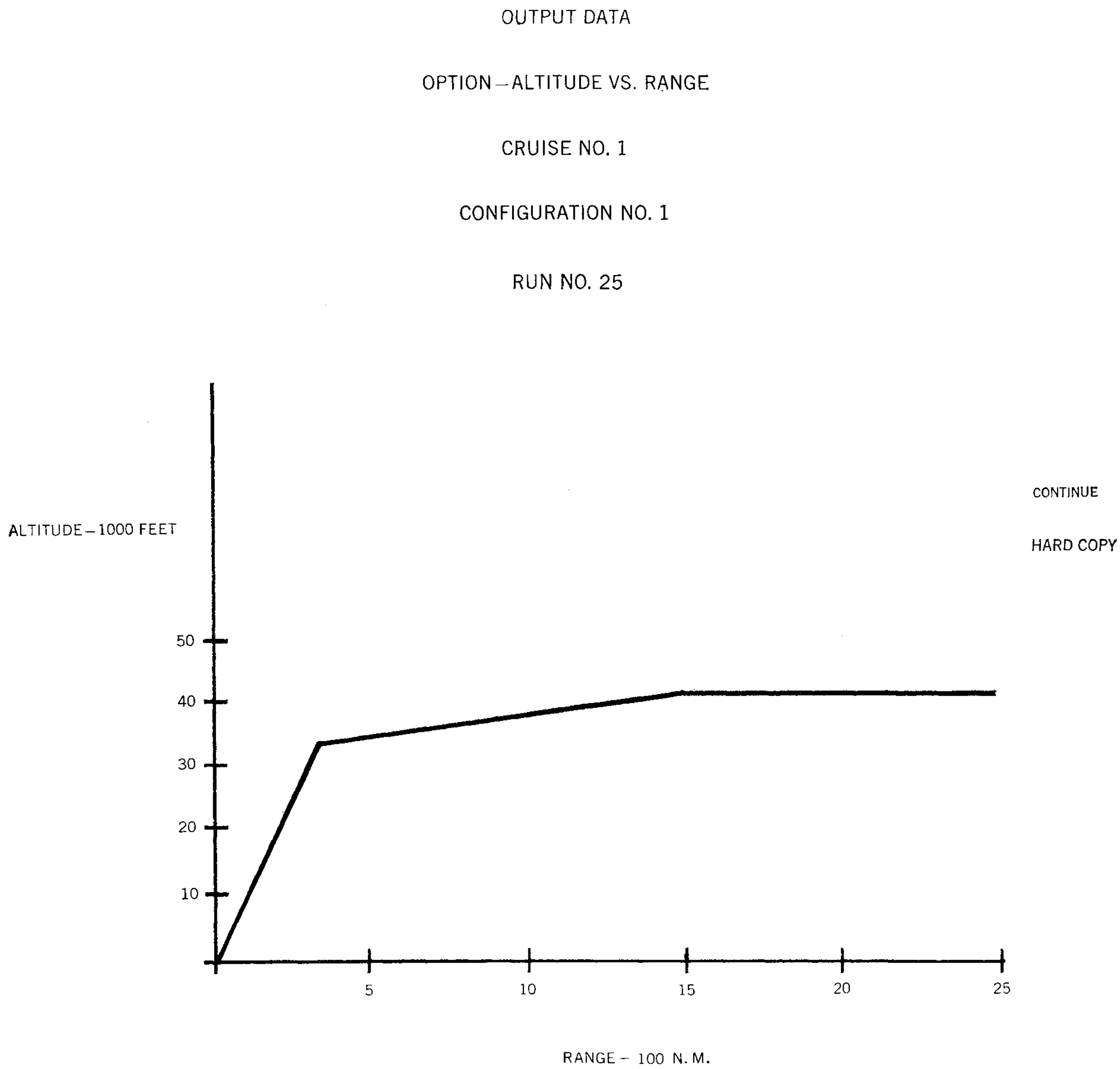

Fig. 11 Typical output of performance analysis subprograms for selected configuration on selected mission.

pal output parameters are aircraft speed, altitude, total weight, and remaining fuel quantity.

The analytical procedures vary from phase to phase; however, each phase uses a process derived from the best techniques currently used for performance analysis. The termination of each phase analysis occurs when specified conditions are satisfied. A climb, for example, may be terminated when a specified altitude is reached, the service ceiling of the aircraft is reached, the altitude for maximum specific range is reached, or a cabin pressure limit is reached.

The results of each mission phase can be reviewed at the termination of the phase analysis, and the results of the total mission performance can be reviewed on the display in several various optional forms. Figure 11 shows one optional form in which the successive altitude-range data points are plotted.

Propulsion System Subprogram

The propulsion subprogram is designed to satisfy three principal requirements, to provide uninstalled and installed performance data for engines for which specifications have been received from the manufacturer, provide a system for conducting powerplant design studies in sufficient depth to establish future propulsion-system requirements, and provide a system for rapidly conducting basic thermodynamic cycle analyses. Only the first of these is implemented at this writing; however, the approach developed to provide propulsion performance of specification engines is inherently appropriate for conducting engine design studies and, with extensions, thermodynamic cycle analysis. The currently operational program permits engine specification data to be scaled up or down in thrust or airflow as desired.

The propulsion-system analysis method was designed to minimize data storage requirements and to maximize flexibility. The system is based on a general cycle analysis. A small number of engine parameters derived from the specification of each engine are maintained in the powerplant library. When engine thrust or fuel flow at any combination of speed, altitude, and power setting are required, these mission parameters, along with the engine parameters, are input to the cycle analysis program, and the thrust and fuel flow are computed. The amount of storage required for the parameter list of an engine is only a fraction of that required to store the performance tables provided by the engine specification, and design and off-design performance can be matched to an accuracy of one or two percent. The propulsion subprogram calculates either the installed or uninstalled engine performance.

A nacelle drag routine is an optional analysis. When a particular engine is selected, pre-established nacelle geometry parameters are automatically transferred to the surface molding subprogram. The nacelle surface is defined and

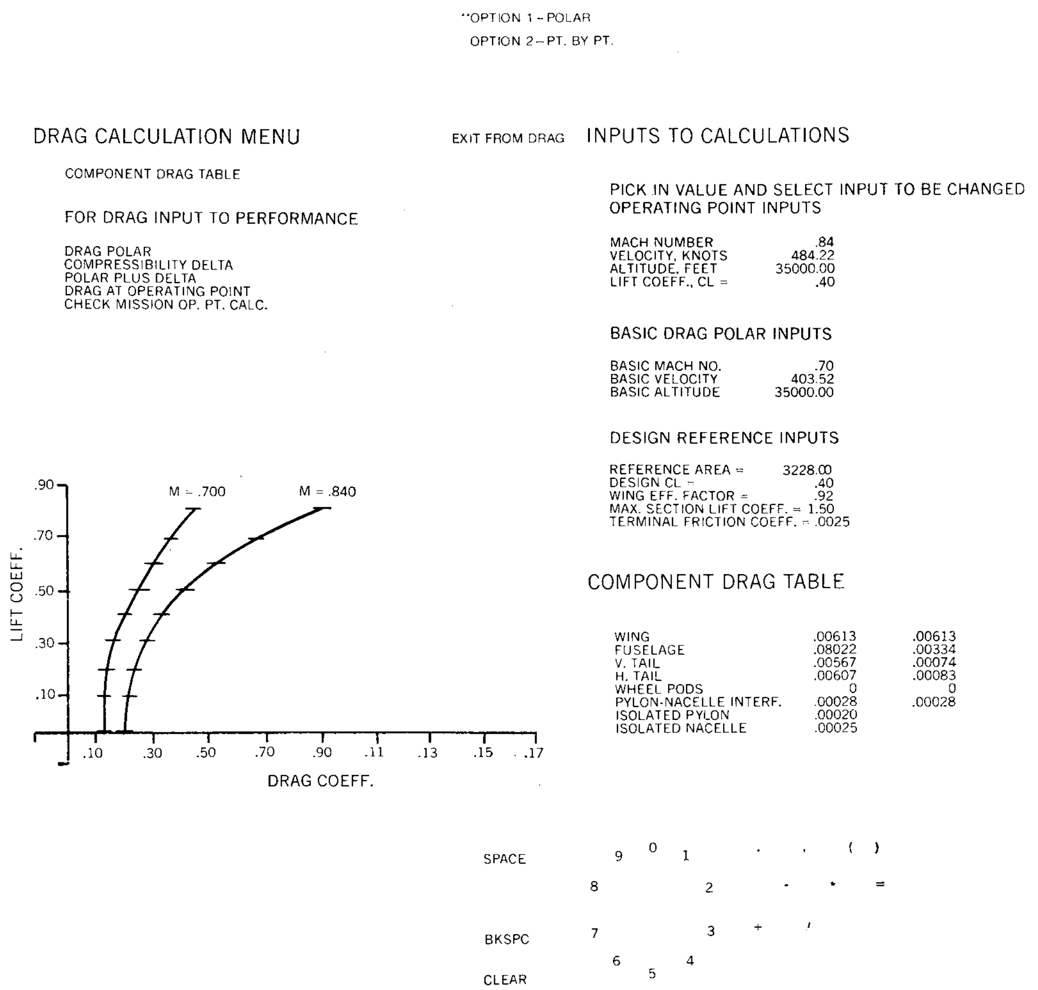

Fig. 12 Results of drag analysis subprogram presented to operator.

presented on the display, where it can be positioned on the configuration. Nacelle geometry is appropriately scaled as the engine is scaled.

A complete nacelle design program is under development. This will tie the surface-molding capability to the nacelle drag and cycle analysis routines, and permit nacelle design to be developed through analytical evaluation of the influence of both the internal and external shape on the installed powerplant performance.

Aerodynamic Subprogram

The aerodynamic drag is computed by summing the parasite drag and induced drag of each component corrected for compressibility. A typical data display of the drag analyses output is shown in Fig. 12. The friction coefficients used to compute the friction drag of each component will be determined by a Reynolds number corrected for changes in altitude and velocity. The induced drag determined during each iteration of each mission phase increment uses gross weight, velocity, and altitude values which have been corrected to account for the changes that occurred in the previous mission increment. Incremental step size is adjustable within each mission phase, so that the analysis precision to analysis time ratio can be optimized. The aerodynamic procedures incorporated into the CAAD system include methods currently used by the Lockheed-Georgia Company Advanced Design Aerodynamic Department.

CAAD Application

The first operational version of the CAAD program is considered to be a prototype of the system and is restricted to the analysis of subsonic aircraft. This restriction is imposed only to limit the investment of manhours in analysis and programming during the initial critique of the system. This CAAD program has been developed as a completely open-ended system. It can readily be expanded into any design and analysis regime, such as V/STOL, supersonic, hypersonic, or into other areas such as missile design or ship design. It can also be extended to handle any level of design or analytical detail.

Development work is presently underway on MCG programs which will interface with the CAAD system in the near future. These include a lifting surface design program, a basic loads program, 2-D and 3-D structural analysis programs, and a section properties and stress analysis program.

A critique of the CAAD system is presently being conducted by the Preliminary Design Division and Advanced Studies Division of Lockheed-Georgia. Initial applications studies will be conducted in parallel with conventional studies to ascertain a quantitative comparison of the technical results obtained from both, the relative elapsed time required to arrive at equivalent results, and over-all economic considerations.

The development of a computer-aided preliminary design and performance estimation capability will open up a new dimension for the aircraft design engineer. In this environment, the man and the computer will form a partnership that has virtually unlimited potential for creative design.

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Human Error Research and Analysis Program (HERAP)

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The purpose of HERAP is to analyze the man-machine-environment system, to synthesize improvements in human performance and, thereby, to attenuate the frequency and severity of accidents. A typical mission was analyzed to map where demands upon the pilot, risk, and accidents are greatest. Existing computer files have been organized into a data bank in order to apply efficiently analytical statistical tools, and to evaluate the validity and reliability of the basic data. Methods are under study to optimize the collection of exposure data. Accident rates adjusted for risk will permit an unbiased baseline from which to judge future performance and attempts to decrease accidents. Emphasis has been placed upon supporting the accident investigator with rapid-access computer files of airframe changes and accident patterns. Work is in progress on how the accident investigator can code his findings to optimize the assistance obtained from such files. Certain data suggest that proper collection of exposure data can, in itself, improve pilot performance which, in turn, is likely to reduce accidents. The total analytical system has been designed to do in days what present methods do in months or years.

I. Introduction

In recent years, the U.S. Naval Aviation Safety Center (henceforth referred to as the Safety Center) has undertaken an all-out attack on human error as a source of naval aviation accidents. This led to extensive planning for a concerted effort on this difficult problem. The later stages of this planning were performed by the Douglas Aircraft Company in fiscal year 1966. Execution of the plan was initiated during the next fiscal year. The purpose of this paper is to report the progress of the two groups, the Safety Center and Douglas.

II. Data Collection

A key task in this work was the collection of data. The Safety Center has kept records on naval aircraft accidents since 1922. Work progressed steadily with these data and culminated in punch-card files that could be processed by machine. Recently, with the aid of a new computer, these records were put on magnetic tape. A part of the concurrent Douglas effort concentrated on analyzing the present and future use of these data, and developing an appropriate data management system.

Before the arrival of the first data file, work began on assessing the present status of naval aviation data summaries, i.e., U.S. Navy Aircraft Accident Statistics (Table 1). These assessments indicated that only accident data were used; i.e., there were no comparisons between the accident and nonaccident segments of the populations. Second, the comparisons were only descriptive; i.e., there were no analytical tests indicating that something was significantly different from anything else. Third, the rates cited were not adjusted for risk. It is well known that landings, flying hours, and

Table 1 U.S. Naval Aircraft annual accident statistics

		Statistics		
		Descriptive		
Table	Title	Totals	Rates	Analytical
1	All Navy flying hours-accident-rates	X	X	
2	Aircraft exposure, accident data and dollar loss by command	X	X	
3	Aircraft accidents by type duty	X	X	
5	Atlantic Fleet aircraft accidents	X	X	
5	Pacific Fleet aircraft accidents	X	X	
6	Aircraft accidents by model	X	X	

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