simultaneously less than 10% and single valued are identified. Note that the primary effect of increasing w_d is an upward shift of the multivalued region along the γ axis.

Conclusions

The problem of predicting the configuration of a cable-drogue system towed in a steady circular path has been reexamined in this paper, and several outstanding research topics have been identified. First, under the assumptions of negligible side and tangential drag forces on the cable, a modeling law for the circular towing problem becomes possible. This law, however, does not preserve flow similarity and its validity must be experimentally determined. Second, for certain ranges of the parameters which govern the problem, the equilibrium solution is multivalued. Little is known about the system response in this multivalued region and the resolution of the behavior there is a question of both mathematical and physical interest.

The primary application of the circular towing concept is in the pinpoint delivery of payloads from fixed-wing aircraft or ships. For the fixed-wing aircraft, this paper has demonstrated an intimate relation between the multivalued regions of solution and the pinpoint delivery regions. Whether or not such a relation holds for the ship problem, where vastly different operating parameters exist, remains to be determined.

References

[1] Huang, J., "Mathematical Model for Long Cable Towed by Orbiting Aircraft," Rept. NADC-AM-6849, June 1969, U.S. Naval Air Development Center, Johnsville, Pa.

[2] Choo, Y., "Analytical Investigation of the Three-Dimensional Motion of Towed Systems," Ph.D. dissertation, June 1970, The Catholic Univ. of America, Washington, D.C.

[3] Skop, R., "On the Shape of a Cable Towed in a Circular Path," Rept. 7048, April 1970, U.S. Naval Research Lab., Washington, D.C.

[4] Lamb, H., *Hydrodynamics*, 6th ed., Dover, New York, 1945.

[5] Casarella, M. J. and Parsons, M., "Cable Systems under Hydrodynamic Loading," *Marine Technology Society Journal*, Vol. 4, No. 4, July-Aug. 1970, pp. 27–44.

[6] Strandhagen, A. G. and Thomas, C. F., "Dynamics of Towed Underwater Vehicles," Rept. 219, Nov. 1963, U.S. Navy Mine Defense Lab., Panama City, Fla.

[7] Wilson, B. W., "Elastic Characteristics of Moorings," *Journal of the Waterways and Harbors Division*, American Society of Civil Engineers, Vol. 93, No. WW4, Nov. 1967, pp. 27–56.

NOVEMBER 1971 J. AIRCRAFT VOL. 8, NO. 11

The Pilot Interface in Area Navigation

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In order to realize the potential advantages of area navigation, the pilot's interface with the system must provide good visibility of the current navigation situation, of the preprogrammed flight plan, and of the system status. It must also permit efficient access for manual changes of the flight plan, utilizing stored data and automated processes insofar as practical to minimize the pilot workload. A control and display unit which provides such a pilot interface is described. It utilizes an alphanumeric display compatible with ATC procedures and a unique form of time-shared controls with logical branching to relevant display data.

Introduction

AREA navigation promises to increase the capacity of ordered airspace. It should also decrease the work load on air traffic controllers by reducing the need for radar vectoring. The increase in complexity of the air traffic route structure will be accompanied by an increase in the constraints imposed upon navigation in vertical and time dimensions as well.

On the surface, it might appear that increasing the number of airways and returning navigation responsibility to the cockpit could decrease pilot work load because voice communications with ATC could be reduced, requirements for heading changes could be anticipated well in advance, geographic location would be known (which is not always true with radar vectoring), and operations in holding patterns might occur less frequently. Similarly, it might appear that automation of navigation switching functions, such that a prestored flight plan could be executed entirely without pilot intervention, would be a major step toward elevating the pilot's role to that of flight manager. Nevertheless, tests to date have indicated that neither area navigation nor automation per se is a panacea for pilot work load problems; in fact, there is an inherent possibility that an inadequate pilot interface with the area navigation system can lead to a substantial increase in pilot work load with a resulting decrease in safety margin. The prevalent opinion that area navigation creates a need for a map display in the cockpit is evidence that this possibility is recognized, but the map display's virtues in facilitating geographic orientation do not seem to relate crucially to the question of over-all pilot work load, much of which involves data input tasks.

The purpose of this paper is to describe the underlying principles and illustrate the approach taken by Collins Radio Company toward reconciling the apparently conflicting requirements for decreasing pilot work load, increasing the complexity of airborne navigation functions, increasing pilot awareness of the navigation situation, and providing efficient access for manual inputs to processes which are largely automated.

Cockpit Information Flow

Basically, the problems appear to us to call for a major reappraisal of the organization of cockpit information flow

Presented as Paper 70-1335 at the AIAA Seventh Annual Meeting and Technical Display, Houston, Texas, October 19–22, 1970; submitted October 9, 1970; revision received June 1, 1971.

Index categories: Aircraft Flight Operations; Aircraft Subsystem Design.

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and of traditional design approaches to the control/display subsystems that are involved. It is perhaps a bit euphemistic to use the phrase "information flow" to describe the mixed bag of data sources, sinks, actuators, and instigators of information transfer that occur in the process of navigating today's transport aircraft. Basic navigation and flight plan data arrive in the form of a satchel of maps and charts, a flight plan TWX, VHF communication exchanges with ATC and company, ATIS broadcasts, weather maps, notes the crew may have made in the flight operations center, and pilot memory. The pilot must make all navigation data inputs manually—course and heading selections, frequencies, climb and letdown paths, altitudes, flight control modes, etc. He must do most of the calculations needed and perform in an "on-line, real time" manner, except when he is receiving radar vectors—wherein he is apt to lose track of where he is.

One of the commonly recognized prerequisites for skilled pilot performance is to stay ahead of the airplane. Traditional navigation equipments have not permitted much of this because there has been presetting capability only to the extent of alternating between number 1 and number 2 systems. Thus, one approach to reduction and leveling of pilot work load is to enable him to define or otherwise operate upon upcoming flight legs in an unhurried manner. This implies that the flight plan should become an integral part of the control/display equipment such that it can be verified, edited, and executed in a single context. This is made possible in the Collins ANS-70 Area Navigation System by means of a magnetic tape cartridge input of all reference data required to construct a flight plan.

Input is only a beginning. A more challenging problem is retrieval and visibility for enabling verification, editing, and instigation of major changes of intent. Our solution to this problem is the avionics control console which displays navigation system inputs, outputs, and reference data while permitting modification by pilot manual entry in the same context as the display.

Control and Display Unit

The avionics control console type of control and display unit (CDU), illustrated in Fig. 1, is derived from over four years of continuous effort to develop a balanced control/display concept for an avionics navigation system. The CRT provides a highly flexible display of numerals, letters, and symbols. An alphanumeric display was chosen because a great deal of the information involved is alphanumeric—both labels and data. Economy of panel area is achieved by using the alphanumeric display to time-share the labeling of a few pushbuttons, and by employing a single keyset for all manual data entries. A relatively large number of display fields were implemented because problems of information retrieval and visibility are compounded severely when one is limited to calling out individually (or in pairs) the data units which are logically related—such as the following items which are required to fly an area navigation route segment: VOR frequency 1, VOR frequency 2, VOR identification code, station altitudes (for slant-range correction of DME), magnetic variations (for correlation to a common coordinate system), way point identification code, way point latitude/longitude, desired altitude at waypoint, course to waypoint, parallel offset from route (when used).

Time-sharing of control elements is found to be highly efficient if access to the desired functions can be gained through logical branching structures. This time-sharing can actually be beneficial because it formats and bounds the areas of pilot choice to those having current relevance. In short, challenges of automatic area navigation have prompted us to undertake development of a revolutionary approach to pilot control interfaces which constitutes a first step toward development of a focal point for a flight management system whose potential ranges more broadly than the navigation problem alone.

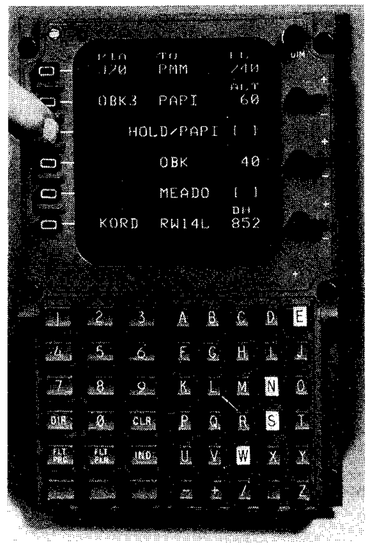

Fig. 1 Control and display unit (CDU).

Background

Touch Tuning System (1967)

Our early experience with a touch tuning system for aircraft communication and navigation radios, demonstrated widely throughout the industry, convinced us that the presence of a general purpose digital computer can be capitalized upon to reshape the pilot's task load in important ways, as compared with his traditional role. However, it became apparent that the power of computerized data storage, search, formatting, and communication could be compromised significantly if the pilot interface design and data store accession strategies did not provide for a common frame of reference for pilot inputs, display of status and progress of automated switching processes.

Simulation testing of the CDU interface with the pilot has been in progress in our Human Factors Laboratory for over a year. This simulation with operational hardware was preceded by over 2 years of analytical studies which served to bring the many operation concepts inherent to this control/display approach into sharper focus.

Analytical Studies

The initial analytical studies reached full expression in mid 1968 in a study whose objective was to determine a maximum practicable avionics integration. The study developed a definition and analysis of pilot work load that brought attention to the need for organizing information flow in the cockpit in a much more explicit and coherent manner. It was pointed out that a major element of pilot work load consists of performing switching tasks in which the pilot serves as an intermediary between a) data on a flight plan TWX, from ATC via voice and from maps and charts, and b) a substantial number of discrete control functions, each with dedicated control/display elements.

With the guiding philosophy that the pilot should not have to perform these switching functions in real time, to the extent that flight objectives can be planned in advance, the task evolved into an attempt to develop a highly flexible pilot control box which would create a compatible interface between a) an essentially automated data storage and switching system and b) manual intervention into these processes. This compatibility should derive from a layout and dynamic interrelationship of control and display elements which enable direct actuation of control intentions within the same context that is used to annunciate automatic switching processes. This control box, which we chose to call an avionics control console, evolved into the form shown in Fig. 2 and was recom-

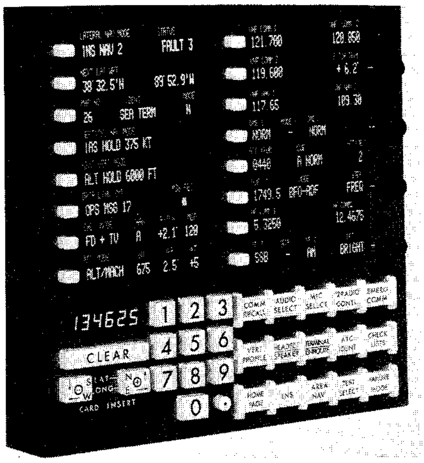

Fig. 2 Avionics control console appropriate for maximum integration of avionics.

mended for installation roughly as depicted in Fig. 3. This particular design concept remains appropriate for highly advanced levels of avionics integration wherein a very large proportion of all avionics control functions are integrated.

The study listed the following as basic features that establish the utility of such a unit: a) Time-sharing of labels of a relatively low number of control actuators (knobs and pushbuttons) as compared with the number of control functions. b) Automatic, rapid, programable page changing. c) The "flight progress page" concept, wherein current status information is available for pilot viewing at all times except during relatively brief cycles of normal data entry or selection. d) Cross-cockpit monitoring and control permitted by eliminating the use of actuators which have inherent positional memory and displays inseparably tied to controls. e) Flexibility via programing to permit tailoring of control display operational characteristics to accommodate preferences of individual customers and future expansion of functions as new sensors and operational requirements evolve. f) Access to blocks of alphabetic as well as numeric data for display and related control purposes, to improve operational visibility of a complex system. g) Opportunity to implement better feedback of pilot actuations, by providing step-by-step corresponding display changes that represent system response rather than simply an indication that the control actuation was accomplished. h) Standardization of operation procedures for accomplishing similar kinds of control tasks. i) Centralization of control of many sensors and computational functions to permit a higher order to controllability through integration and complementation.

In all, the contents and operational logic of 52 kinds of CRT pages of control functions were described. It was shown that access could be attained in a logical, straightforward, rapid manner. At the same time, it was emphasized that the implementation of such a control box must be scaled to reflect the following dimensions of the system being controlled: sensor complement (including projected growth), functions available for control, priorities for accessibility of control functions, assignment of duties among crew members, redundancy requirements in control.

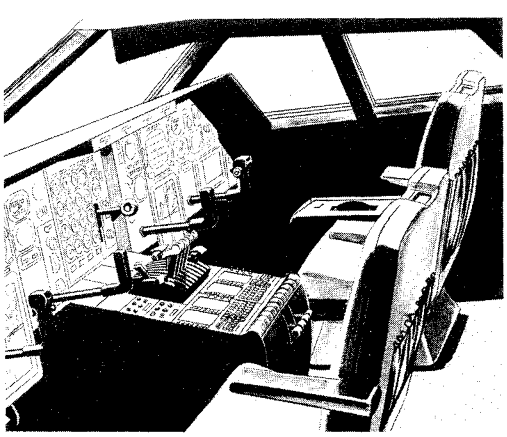

Fig. 3 Recommended location for avionics control console.

Recognizing these factors, a second design of control box was proposed in the same report (Fig. 4). This design retained all of the basic concepts but reduced the CRT display area in number of control functions integrated. This reflected a concentration upon navigation switching tasks as the area most urgently requiring automation.

One interesting outcome of this study was an indication of the panel area that might be saved by this approach to avionics control. The summary is presented in Table 1 and refers to the box design shown in Fig. 2. It is shown that panel area requirements are cut to under one-third, even though eight major classes of growth functions—having no conventional control box design yet established—are added in the case of the avionics control console.

Human Factors Studies

At this point, studies with operational hardware were undertaken in two areas: a) basic data relating to possible problems in using a keyset as a cockpit data entry device. Although this was being done in ARINC 561 INS systems, there were no data available suggesting how far one might want to extend such a concept, what penalties in time and errors might derive from such designs, nor what sets of key design parameters would minimize errors. b) A general purpose simulation facility in which a wide range of variables relating to this general type of data entry/display method could be investigated.

The differences between the CDU design in Fig. 1 and that of Fig. 4 reflect the following influences to which we have been responsive: a) Adapting the concept to the specific requirements of an ARINC Mark 2 Area Navigation System (ANS) affected: functions controlled, growth requirements, necessity to operate in near-term ATC environment, cockpit mounting space available in wide-body tri-jet aircraft, data base organization, pilot role in constructing a flight plan, monitoring and annunciation philosophy. b) Inputs that we have received in detailed interactions with airline personnel, particularly with respect to degrees of relative emphasis placed on various functions. c) Our experi-

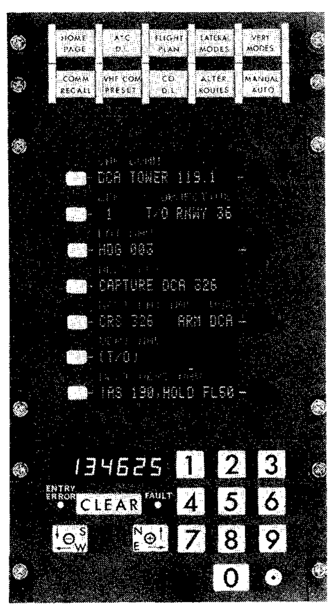

Fig. 4 Integrated control and display unit recommended for 1972 prototype.

ence in the CDU simulations. d) Our experience in basic keyset data collection. e) Our analysis and planning for implementation of a completely operational system in a Collins aircraft (Grumman Gulfstream I).

The cockpit mockup and equipment used in the CDU development simulations are shown in Fig. 5. The following issues have been studied and resolved.

Need for special function keys

It can be seen in Fig. 2 that we started out with 15 dedicated function keys. This was scaled down to 10 in the second version. We had not yet happened upon the very useful Page Index concept and, consequently, were still assigning a special function key to every class of page or operation that had no direct association with a Flight Progress Page function and thus could not be reached by branching from this page with a line select key. In our latest designs we retain eight special function keys (of which three are spares with no designated function at present) and see little need for more, inasmuch as the limited panel area available can be allocated to much better use, and branching through several page levels is very rapid and straightforward.

Keyset entry scratch pad

A separate display module originally used for the keyset scratch pad function is wasteful of panel area, especially if it were expanded to the 16 characters available when a line on the CRT serves this purpose. Entries of latitude/longitude pairs are feasible with a 16-character scratch pad, and this is a very appealing capability. Also, discrete scratch pad display elements appropriate for the alphanumeric keyboard are impractical to implement.

Table 1 Approximate panel area and volume advantages of avionics control console

Conventional control panels	Total[a] area, in.^{2}	Total[b] volume, in.^{3}
VHF Nav, DME; VHF comm; VHF comm preset; HF comm; ATC transponder; SELCAL; SATCOM; Weather radar; Area nav; INS display (including waypoints); INS control; FCS data; Multifunction display (control only); EADI (control only); Audio; ADF	630	4100
Avionics control console	**Total[a] area, in.^{2}**	**Total[b] volume, in.^{3}**
All of the preceding functions *plus* the following: Map display (control only); Test sequencing and fault annunciation; Cross-cockpit control/display; Lat/Vert Nav waypoint presets (in addition to INS; Data Link input/output; Checklist display with sequential verification; Bulk data entry; Access to blocks of data with alphanumeric labels	190	1600

[a] Captain and first officer panels.
[b] Connector depth included.

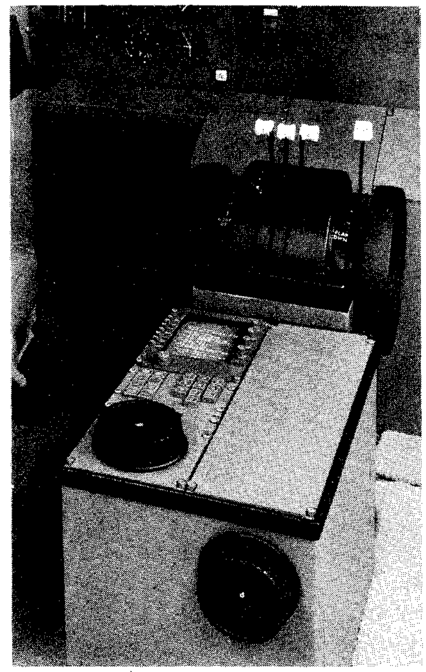

Fig. 5 Cockpit simulator with CDU installation for control/display studies.

Vertical modes

One may note in the photos from the avionics integration study that vertical and lateral axes were handled separately. It has since been determined as inconceivable that a pilot would maintain separate vertical and horizontal flight plans. They should be interleaved into a single flight plan.

Reduced size of display

Having experienced a number of design exercises relating to various systems, we have concluded that six pairs of label and data lines plus scratch pad are adequate for foreseeable control requirements and will improve the pilot's ability to sort out what he is looking for, compared with larger displays. However, the number of filled page formats required for MK 2 ANS control convinces us that one would be ill-advised to reduce the number of lines still further. Six line pairs of data appear to be a good compromise among the myriad of competing considerations.

Reduction in number of characters per line

The pages developed for the ARINC Mark 2 ANS control demonstrate that the 16 character line is very efficient in handling all display fields and clusters. Additional crowding of characters laterally degrades readability.

Method of writing characters

The dot matrix characters produced by a raster technique prove to be hard to read and inefficient of beam writing time. The stroke method that we have developed promises to provide better readability by virtue of character shape and perceived brightness.

Leg numbering

Some way point structures studied have used leg numbering in a manner somewhat analogous to the way present

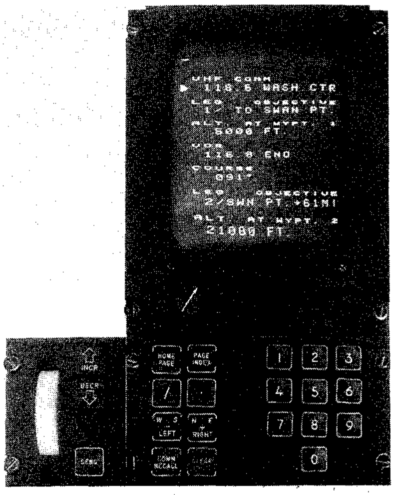

Fig. 6 CDU with cursor module.

ARINC 561 INS controllers number way points, except that we considered a system with sliding numbers wherein the present leg would always be leg number 1. This approach may have merit in very simple area navigation systems wherein the pilot inserts leg data piecemeal, from cards or keyboard, but it appears to be a wholly unnecessary and confusing intermediate indexing scheme for a system having the capabilities described herein. The *FLT PLAN* and *FLIGHT PROGRESS* pages provide adequate supporting context to sustain pilot awareness of way point sequencing.

The following features have been specifically upheld and shown to have considerable utility.

Label line/data line format structure

The label lines provide needed structure in a system with many pages. Their use can be limited to functions when they are really needed, such as above demarcated blank spaces in a page which is organized as a form for manual entry. They can be overused wherein data are self-identifying by their inherent organization. In any case, the presence of label lines does not constitute a waste of CRT area because the spacing of data lines is at the minimum acceptable, due to the presence of line select keys.

Line select keys

These keys provide a very direct way to designate a line for keyboard entry or for page branching. Other methods of line designation studied include a remotely operated cursor in the left-hand character column (see Fig. 6) and scrolling of the page to a standard entry line. The latter approaches place unnecessary overhead on sequential page branching operations, inasmuch as the number of control actuations per branching is doubled.

Increment/decrement control

This function proves to create a human interface with a digital computer which is remarkably similar in operation with the traditional analog knobs. Line feed, page feed, and the ability to make small changes in large numbers have been shown to have major utility.

Page chaining into sequences

Page chaining permits time-sharing of line select keys as function selectors. This has been shown to be very straightforward, enabling rapid access to a very large number of control functions. This is a major element in this CDU's flexibility and potential for growth.

Tabular input structures

A table or form, such as Fig. 7, is readily appreciated as an extremely straightforward, familiar manner in which the pilot can be led through required data entries. The associated logic can place required constraints upon values entered and can prevent activation until all required data in a group have been entered.

Control/Display Functions—Hardware

The basic CDU, Fig. 1, consists of the following elements at the pilot interface: a) an alphanumeric CRT display with 13 lines of 16 characters each; b) an alphanumeric key set; c) three symbol keys (+ − /); d) five special function keys: flight progress page (FLT PRG), flight plan page (FLT PLN), page index page (IDX), "direct to . . ." (DIR) and clear (CLR); plus three spares; e) six "line select keys" adjacent to the left-hand side of the CRT; f) three increment/decrement levers adjacent to the right-hand side of the CRT; g) a CRT brightness trim knob (supplementing the automatic dimming); h) two hidden legend annunciators as follows: 1) FAULT—denotes LRU failures, elaborated on LRU STATUS page of the display; 2) ALERT—denotes radio alert, sensor submode change, or way-point alert, as elaborated on the CRT display.

The primary factor determining the choice between numeric and alphanumeric keyboards relates to orderliness of air traffic control in the areas to be flown. To the extent that a large majority of flights are made on published routes and in accordance with predictable flight plan segments, the numeric-only version is preferable because it presents a simpler physical interface to the pilot, provides more structure to his decision making processes, and can require fewer key actuations. Whether or not the reduction in key actuations is of significant magnitude depends upon the extent to which the automatic data search and listing functions used with a numeric key set version are retained when alphabetic keys are made available. It must be noted that, in the extreme, an alphanumeric keyset CDU can be programed to operate exactly like a numeric-only version, with the alphabetic keys not used. The alphabetic keyboard makes route and way point nomination more straightforward; thus, this keyboard has appeal in operations wherein diversions from prestored flight plans are relatively common. This keyboard may also offer special advantages in future air-to-ground data link operations, insofar as it may be necessary to enter the names of places for reference. What must be determined is the manner in which the straightforward linguistic aspects of alphabetic entry can be reconciled with the desire to minimize manual entry demands and pilot input errors.

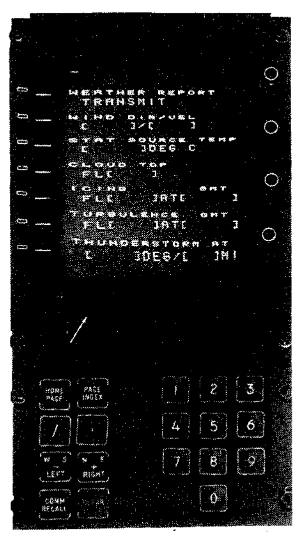

Fig. 7 CDU display page structured as a form for data insertion.

The fixed CRT line structure contains a "scratch pad" line at the bottom, plus six "label line/data line" pairs. A "line select key" is associated with each of these line pairs. An increment/decrement lever is associated with the second, fourth, and sixth line pairs. All actuations of symbol keys are displayed immediately, in sequence, on the scratch pad line, and line select keys serve both as INSERT keys (when data are in the scratch pad line) and alternatively as a source of discrete messages to the NCU (when the scratch pad line is blank). The latter function is central to the efficiency of this control approach inasmuch as the alphanumeric information on the CRT serves to provide labels for the line select keys so that "pages" of labels create a functional equivalent of a large number of dedicated pushbutton switches, grouped into sets of mutually exclusive control states available for selection.

Label line contents, and brackets within data lines (where appropriate), indicate the fields within which manually entered data may be transferred from *Scratch Pad Line* to a *Data Line*. The slash (/) key serves as a field separator, so that more than one data field may be entered into a line in one actuation of a *Line Select Key*. When the NCU detects an entry error (an entry which is inappropriate because of context or magnitude for the line selected), the *Scratch Pad Line* does not clear and *Error* is annunciated. The *Clear* key resets the annunciator and clears the *Scratch Pad Line;* however, if the apparent entry error was due to depressing the wrong line select key for the data on the scratch pad line, subsequent selection of the correct key will transfer the data to that line and cancel the *Error* annunciation, without requiring use of the *Clear* key.

Control/Display Functions—Software

Basic Concepts

Several concepts represent the basic organization of software routines related to CDU operation: a) The *Flight Progress Page* is the prime display. Normally, the pilot observes this page to monitor present status and progress of navigation and of the area navigation system. Manual data entries can also be made as appropriate. Departure from this page may be accomplished in one of two ways, by actuation of a line select key for branching to a page of logically related data or alternatives, or by actuation of a dedicated special function key, namely *Flight Plan* or *Page Index*. The bottom line of the *Flight Progress Page* is reserved for annunciation of submodes and of automatic switching of sensor control status. b) The *Page Index* is a listing of page types which cannot be accessed by dedicated function keys or by line key actuation on some other page. c) The *Flight Plan* page is a master listing of the series of way points that will be flown. The pilot's flight planning task consists of constructing and editing this listing. The page begins with the From way point and has indefinite length (up to a maximum of 60 way points) made possible by the *Line Feed* function (see below). Actuation of line select keys adjacent to way point names (or adjacent to a blank space following a way point list) will cause a branching to a *Flight Plan Revise* page which is a list of alternative ways in which flight plan modifications can be made. Once a selection is made on that page, branching occurs to another more detailed subsidiary page or back to *Flt Plan,* as appropriate. With alphabetic keys, the *Flt Plan* page can be operated upon directly for changes in way points and routings which are part of the data store. d) The *Line Feed* function is one use of an increment/decrement lever for rolling a displayed list upward and downward, analogous to moving a strip of paper behind a window. e) The more general *Increment/Decrement* function is a floating reference capability for making small changes in numeric values (for example, planned altitude at way point). f) When a group of manual entries are interdependent (for example, basic data defining a VOR station), the page cannot be executed until all required entries have been made; otherwise, *Error* is annunciated. g) The *Clear* key clears the scratch pad line and resets the *Error* annunciation. h) The *Dir* key is used to command a change in the flight plan to go from present position direct to the waypoint designated subsequently either by use of a line select key adjacent to a waypoint on the *Flight Plan* page, or by entry of the waypoint ident via the alphanumeric keys. i) *Automatic Page Change* occurs when entries on subordinate pages can be logically established as completed. For example, way point definitions from basic data cause automatic return to *Flight Plan* page, where the result can be viewed in context. j) Way point and fix inputs from a map display are placed in context within appropriate CDU pages. These inputs are shown as latitude/longitude on the CDU for visual verification prior to manually initiated retransmission to the NCU. k) *Blinking* is a software feature which permits appropriate character groups on the screen to be displayed and erased intermittently, to provide annunciation functions.

Page Content

Types of page contents can be summarized as follows: a) Stored reference data, used by the computer for navigation and available to the pilot for retrieval and editing (for example, in response to NOTAM information); b) stored route/airways data needed by the pilot to create flight plans; c) current navigation strategy; d) prevailing system control and LRU status; e) prevailing computational outputs (flight performance data); f) preflight test sequencing; g) lists of optional page titles available for retrieval; h) communications preset frequency list (optional); i) forms for manual entry of raw data; j) data received from map display.

CDU Philosophy

When we speak of a balanced control/display approach we refer to balance among a considerable number of factors, including the following design dimensions: a) number of character spaces in display area, b) display character repertoire, c) manual input character and code repertoire, d) method of accessing stored data, e) methods of entering data manually, f) data accession times, g) techniques for discrete annunciations.

With respect to these dimensions, many shades of emphasis are possible. We have chosen a set of design criteria that emphasize the automatic character of the navigation system, giving rise to an important requirement for straightforward pilot intervention into these automated processes. The following example will clarify this point:

The basic data store contains data defining, among other things, company flight routes, airways, and radio facilities. A small number of pilot manual entries can cause a lengthy flight plan to become established. This flight plan can be flown completely without pilot intervention insofar as no route changes are made.

Capability to display a significant number of way points at once on a *Flight Plan* listing should facilitate pilot search efficiency for verification and for editing, by providing a broad visual context. Capability for showing a complete block of interrelated flight reference or performance data will simplify search strategies and reduce search time. Thus, a relatively large display area was deemed a requirement.

The presentation of such a listing in common ATC terminology has the appeal of solid familiarity to experienced pilots, thus reducing the probability of errors, compared with the introduction of new codes that might be imposed. An alphanumeric display character repertoire is thereby implied.

Numeric vs Alphanumeric Keyboard CDU

The character and code repertoire required for manual input depends upon the efficiency with which search strategies can be implemented, and upon the extent to which manual input requirements can be constrained in general to small, logically related, mutually independent sets of alternatives.

The following list of system characterizations tend to favor the numeric only approach: a) computerization imposes an inherently logic operational structure upon the navigation system. b) Indexing of the reference data store requires rigorous discipline in its organization. c) Spatial interrelationships within routings and airways networks, viewed in light of aircraft performance limitations, place rigorous constraints upon the sets of credible control options available at any particular time and with respect to any particular flight location or situation.

With the numeric only keyboard, the line select keys and the increment/decrement levers provide the control functions that might otherwise require alphabetic keys; these control elements play the central role in enabling logical branching as the basic accession approach to the very sizable data store. Such a branching approach to data accession is unworkable if retrievals are slow. That is, it is central to our control/display approach that several display "pages" may be called up in a sequence to achieve a control objective. Thus we have emphasized a system organization that enables very rapid search and transmission.

This branching philosophy applies also to the CDU version with alphanumeric keys, but in this case the amount of branching required can be reduced. When a large percentage of flying is done on predictable, prestored flight plans, this ability to enter routes and way points by their names, directly, trades off unfavorably with the following penalties which are derived: a) The pilot is confronted with a much larger set of keys, increasing the probability of entry errors, and introducing the task load of recovering from such errors. b) Flight plan entry becomes less structured, thus introducing the possibility that the pilot will enter the names of route segments which are undefined in the data storage. Conversely, the pilot may remain unaware of desirable routing alternatives that would have been retrieved in an automated search. c) Operation of the alphanumeric keyset can require more key actuations than does the numeric keyset.

On the other hand, the numeric only CDU results in entry sequence overhead which can become burdensome if the flight plan evolves capriciously in near real time by virtue of the aircraft's being vectored from place to place by ATC. So long as the aircraft stays on prestored flight plans or on known route segments for reasonable durations, the task load should be acceptable.

Operational Guidelines

Specific operational guidelines applied to the design of the CDU include the following: a) In the aggregate of all types of pilot manual input requirements, the number of control actuations required should be an absolute minimum. (Thus, even with the alphanumeric keyset version, a considerable amount of page branching is retained because of its efficiency in focusing upon control alternatives listed in plain language.) b) To the greatest extent possible, the CDU should lead the pilot step by step through manual data input and control sequences, visibly constraining choice only to credible alternatives and performing a maximum of validity checks upon inputs prior to their execution. c) All data required for navigation along company flight routes, defined airways, within VOR and/or DME defined airspace, and with respect to inertially defined way points must be available and accessible through the CDU, displayed in standard terminology so as to eliminate the need for code tables and the like, other than standard flight plans, clearances, and approach charts. d) To the greatest extent practicable (consistent with pilot requirements for rapid access to control and display functions) the design of CDU hardware should not reflect peculiarities of operational requirements relating to the imponderable elements of future ATC network organization, nomenclature, communications media (acknowledging growth potential to data link), and dimensions (acknowledging growth to vertical path preprograming and time navigation). e) Provision should be made for alphanumeric display area, character repertoire, and writing speed commensurate with all foreseeable requirements. In particular, the display area is dictated by the size of data blocks identified as logically related, therefore accessible ideally in a single retrieval operation and viewable with a minimum of manually operated scrolling (line feed or page feed). f) The number of different controls should be mimimized, consistent with requirements for efficient access. This applies in particular to dedicated function keys. g) Features should be implemented to combine uniquely the ability to call up lists of credible alternatives for display—such as alternate routes—and the ability to designate directly, within the context of that list, the control status changes desired. h) Entry error problems should be countered in the following ways: 1) create an entry structure that is unambiguous, by virtue of labeling, logical coherence, and size of context. 2) Constrain control actuation choices available, and provide rigid formats within which to enter data. 3) For every control actuation there should be immediate display feedback. 4) Implement automatic range, increment, and reasonableness checks on entries. 5) Alert the pilot at each point that automatic (preprogrammed) switching is to occur. 6) Standardize upon the logic and actions by which entries are made for different purposes. 7) Design the physical control and display elements in keeping with good human engineering practice. i) Means should be provided for making small changes in large numeric data fields without the necessity of re-entering the entire data field. This reduces the probability of gross errors in re-entry and can be particularly appropriate in the case of latitudes and longitudes. j) Provision should be made for straightforward ways to display lists of indefinite length, without the discontinuities of page numbering or other devices. k) It should be possible to verify all numeric and map display way point and fix inputs visually, prior to use by the NCU for navigational purposes. l) As an end result of all the preceding criteria (having the purpose of task simplification, entry time reduction, and absolute minimum possibility of undetected pilot errors) the initial and continuing training requirements necessary for proficiency in operating the system should be minimized.

Conclusion

A concept for an avionics control console utilizing an alphanumeric display and time-shared function controls has been presented, with a discussion of the operational aspects considered in applying this concept to the control and display unit (CDU) of an ARINC Mark 2 Area Navigation System. The detailed CRT page formats which define the exact operational capabilities and sequences of this CDU are somewhat dependent on the specific requirements of the user, and are beyond the scope of this paper.

The CDU described is now being flight tested in a Collins aircraft. It provides the major control and display functions for the area navigation system, including waypoint, route, and altitude selection for constructing the flight plan, automatic tuning of the VOR/DME radios, and control of the inertial sensor system (ISS). It will also provide the pilot interface with a ground-air-ground data link, providing both an alphanumeric readout of messages received and a repertoire of canned messages to be transmitted, with pilot entry of specific data.