Computer Flight Planning in the North Atlantic

LEROY SIMPSON,* DOUGLAS L. BASHIOUM,† AND EDWARD E. CARR‡
Aero Performance, Inc., Manhasset, N. Y.

An electronic computer and communications system, using the IBM 1620, is developed to provide rapid analysis of upper-air winds and temperatures, optimum route and altitude selection, and detailed speed, time, and fuel data for the preflight planning of jet transport operations over the North Atlantic. The computer flight planning process, program development and operation, facility requirements, meteorological data input, and program capabilities are described. Experience in application of the system to planning daily flights of B707 and DC-8 aircraft for several airlines operating the North Atlantic has demonstrated high accuracy and precision of data handling procedures with reduced exposure to manual errors. The system offers greater flexibility for multiple-plan computation and exploration of alternatives in routes and altitudes, as well as substantial improvements in operating efficiency and economy resulting from increased precision in track determination and optimum plan selection. The potential of a computer flight planning system (CFPS) for application to other areas and services is outlined. It is seen to be an important step in the desired, if not essential, automation of all operations data analysis and planning to keep pace with the advances in technology in navigation, communications, and flight equipment.

APPROXIMATELY 150 jet aircraft, operated by the international airlines, now take off each day for flights across the North Atlantic. Flight planners for 23 operators that fly between North America and Europe work at preparing detailed flight plans for each of these trips. They all analyze weather forecasts in an attempt to find the most favorable route to follow; they all leaf through volumes of aircraft performance data to determine the flight altitudes that may be scheduled; they all calculate speed that will be realized and the fuel usage resulting from one or more of several modes of operation which may be used for the plan.

Need for Planning

Each flight has a planning objective. The objective may change from flight to flight, from day to day, and season of the year. It may also vary between routes, operators, and aircraft types. The "optimum" plan for any particular flight will be one that meets one or combinations of such objectives as ability to haul required payload, most economical conduct of the flight, arrival within scheduled time, or possibly to produce the fastest flight, all within the requirements to provide safety and passenger comfort.

The importance of choosing the best route and developing an optimum plan becomes apparent when considering that a plan that will save 1 min of flight time, may save a minimum of \$3 (the cost of a minute's fuel), or as much as \$300 (the revenue from a passenger), when this reduced fuel requirement prevents turning him away.

A second requirement of the planning effort is to provide the pilots an accurate and detailed account, i.e., a "flight plan" of the route, altitudes, air speeds to be flown, and the winds, temperatures, ground speeds, times, and fuel burnout to be expected between each significant check point in the flight.

The computations involved in jet flight planning, are not excessively complex. An extensive amount of wind, temperature, air route, and aircraft performance data must be analyzed, however, to produce a complete and adequate flight plan. When calculations of all flight planning variables are done manually, there are distinct limitations on the number of alternatives that may be explored, and on the speed with which revised plans may be produced to cope with rapidly changing conditions. This is especially true in light of the requirement to perform the flight planning function within a relatively short time prior to the departure time of the flight, in order to allow use of the most current weather and other operational data.

Need for Computers

Since the days prior to World War II, when the earliest trans-Atlantic air services were begun, little advance has been made in the techniques used in the preflight planning of long-range over-water operations of transport aircraft. True, flight planning has improved as a result of improved meteorological data and the advent of faster, longer-range aircraft, but the advances in technology, which have been applied to the operation, communications, and navigation of jet aircraft, had never appeared in the flight planning function.

Today the modern digital computer can perform high volume calculations accurately and rapidly and make logical selections between alternatives. These machines have the ability to perform an impressively greater number of analyses within a limited time than possible by manual calculation methods. Such capabilities make computers eminently suitable for application to the aircraft flight planning function.

The successful application of the electronic computer into other areas of aircraft operations, including their use by individual air carriers for less complex domestic planning, inspired the development of a system to provide the following features for jet operations over the North Atlantic: 1) rapid, accurate assimilation of latest possible weather data for all operational routes and altitudes; 2) rapid, accurate determination of operational minimum time tracks meeting all requirements of authorized airways and oceanic air route traffic control; 3) analysis of standard and alternative cruising techniques to provide an operation best suited to the planning objective of each flight; 4) specification of best flight path altitude profile within the weight and temperature limitations on aircraft performance; 5) computation of multiple flight plans for selected alternative track and operational altitudes; 6) selection of optimum flight plans to meet such planning objectives as minimum operating cost, least fuel (greatest payload) requirement, or fastest flight; 7) summary data outlining fuel requirements, flight times, and operating costs of nonoptimum track and altitude alternatives; 8) generation of "reclearance" planning data for operations

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* President. Associate Fellow Member AIAA.
† Programer. Associate Member AIAA.
‡ Meteorologist. Member AIAA.

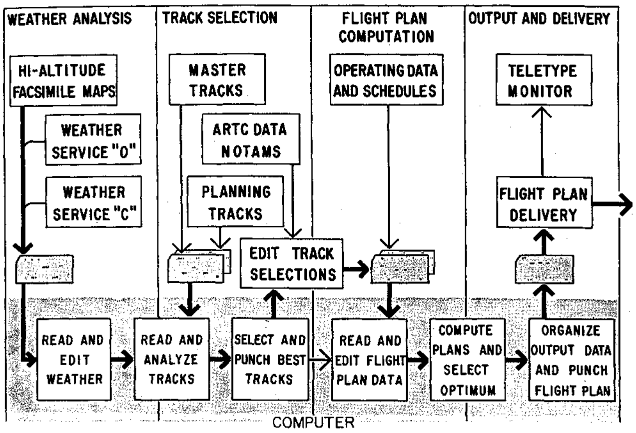

Fig. 1 Computer flight planning operating sequence.

limited by maximum weight or fuel requirements; and 9) flight planning data in a format customized to each operator's specifications.

Such a system was conceived as having the potential for offering the economic benefits of fuel savings, time savings, and increased payload potential on each flight. It was also seen as a valuable tool to expand the capability of dispatchers and pilots, to provide analysis of a heretofore unavailable scope of information relating to the operating potential of each flight, and to bring about an over-all improvement in planning efficiency and operating economy.

The CFPS described here is the culmination of a three-year development effort. The quality of meteorological data, the availability and cost of facilities, the benefits and marketability of such a service were studied during this period in relation to the growing volume of jet traffic on the North Atlantic. In July of 1962, a separate organization, Aero Performance, Inc. (API), was established jointly by Rand McNally and Company and R. Dixon Speas Associates to continue work in this area. In February 1964, the API-CFPS started functioning with trial operations. Full-time service began on July 1, 1964, and by the end of the year it was in use for the North Atlantic jet operations of four international airlines.

Planning Data Requirements

The flight planning process for long-range jet operations requires the assimilation of large amounts of operating data to permit selection of the best route and computation of the best plan. These data requirements are in five major areas: 1) weather conditions forecast to exist on the route at the time of the planned operation, 2) authorized route information showing the airways, check points, track headings, segment distances, and flight altitudes usable within the limitations of air traffic control (ATC) requirements, 3) performance information for the specific aircraft types involved, showing climb and descent data, altitude and speed capability, and fuel consumption requirements for each desired cruising technique, 4) plan data appropriate to each flight specifying the aircraft weights and limitations, reserve fuel requirements, flight origin and destination, desired payload, and flight plan objective, and 5) the planning procedures established for use of weather information, track data, performance data, and specific plan data, to reflect the operator's policy in establishing and realizing planning objectives.

The high-altitude forecasts for the North Atlantic produced by the U. S. Weather Bureau (USWB) are used as the basis for flight planning by all but one of the air carriers for planning eastbound operations across the North Atlantic. The CFPS is designed to incorporate these USWB data directly into the system, with only a limited amount of additional special forecast data required for westbound planning.

The track information developed for input to the CFPS is derived from data supplied by each operator. Only those routes specifically designated in each carrier's operations manual are processed, so that resulting track selections will be in full compliance with the requirements for adherence to authorized airways and other restrictions that may be imposed by each airline. All mileages are those specified by each operator (even including the differences in operator's mileage data between specific over-ocean points).

Performance information is generally made available to the flight planner in the form of an aircraft operating manual. These manuals generally include extensive data relating to the climb, cruise, descent, and altitude holding capabilities of the specific type. The equivalent of these data are prepared for the computer system in the form of equations. The exact form of the equation will depend on the type of data and accuracy required. They are generally empirically derived.

The system is designed to take maximum advantage of the speed at which detailed flight plans may be computed. The variable data appropriate to each flight need only be input a short time prior to the time that plans are required by the operator. Each airline retains control over the system output, since the source of all variable plan data is the airline dispatcher/operations controller.

The procedures established by each operator for the development of preflight plans are normally included in the company operations manual. These procedures specify the manner in which all planning information will be processed, the types of cruising techniques authorized for planning, the basis for computing time and fuel requirements, and the detailed procedures for completing a flight plan document. In the CFPS this function is accomplished by the stored program that determines the manner in which the flight plan calculations will be made, selected, and formated to meet the specifications of each airline.

Computer System Facilities

The computer system has been designed to accomplish the North Atlantic flight planning process in the following four main steps (Fig. 1): 1) collect and analyze the appropriate meteorological data, 2) select the best route (track) to follow, 3) compute plans and select the optimum plan for the flight, and 4) deliver plans in a format and in a schedule required by each airline. The facilities that have been assembled to perform these steps on a continuing basis with speed and reliability include the following (Fig. 2):

1) Input facilities to provide connections to the source of weather data and operational information needed for the system:

a) USWB High-Altitude Facsimile Network (HAFN): Transmits prognostic charts from the High-Altitude Meteorological Service of the USWB and the National Meteorological Service of Canada. Every six hours, forecast centers located at San Francisco, Anchorage, Montreal, Miami, Kennedy International Airport, and the National Meteorological Center at Suitland, Md. transmit a set of "prog" charts, each concerning their respective areas of responsibility.

b) USWB Service "O" Teletypewriter System: Latest upper-air, wind, and temperature observations from Canada, the North Atlantic weather ships, and from Europe are available on this circuit, as well as current reports from aircraft flying over the North Atlantic.

c) USWB Service "C" Teletypewriter System: This system is the source of upper-air, wind, and temperature observations used to monitor the forecast weather data for that portion of the United States included in the computer input.

d) Federal Aviation Agency (FAA) Aeronautical Fixed Teletypewriter Network: Provides significant data on airspace reservations for military activity, operational status of facilities, and preferential routing information from traffic control centers.

2) Processing facilities to perform all of the data handling and computation required for the system:

a) IBM 1620 Data Processing System: It is a solid-state (fully transistorized) electronic computer. It contains 20,000 digits of magnetic core storage capacity, recognizes 37 different commands, and has an unbuffered typewriter that can be used for input and output. It uses a card reader capable of reading 250 cards/min and a card punch capable of punching 125 cards/min. API initially used a unit containing an additional 40,000 characters of magnetic core storage, thus giving the 1620 system a capacity of 60,000 characters. Conversion to model 1311 random access magnetic disk storage has recently increased total storage capacity to 2,020,000 characters.

3) Output facilities to provide for rapid delivery of computed flight plans:

a) Aeronautical Radio, Inc. Teletypewriter Circuit: An automatic 100-word/min circuit provides local delivery of computer produced flight plans on a teletype printer in the operations/dispatch office of each airline served by the system.

b) IBM 1912 Telegraphic Card Reader and Punch: It is used to read the output cards from the computer flight planning program (CFPP). Data are electrically converted from the 12 channel code in IBM cards to 5 channel code for direct transmission into the teletype circuit. Thus, the delivery of flight plans is fully automated without a requirement for manual teletype operation or preparation of the usual paper tape.

Weather Analysis Procedures

Weather forecasts used by almost all international air carriers flying from the East Coast of the United States to Europe are those prepared by the forecast center at Kennedy International Airport, and transmitted to users over the USWB-HAFN.

In order to provide the track selection and flight planning program with the upper-air forecast information required for jet aircraft operations, data from these "prog" charts are required as input to the computer. At each of the selected weather input points over the ocean and at various airways intersections and terminal points, the following elements are recorded: 1) 300-millibar (30,100 ft) wind direction and velocity and temperature, 2) 500-millibar (18,300 ft) wind direction and velocity and temperature, 3) vertical wind shear per 1000 ft, 4) tropopause height and temperature, and 5) 150-millibar (44,600 ft) temperature.

As the maps are received on the facsimile recorder, the values are manually transcribed onto data sheets and then punched on IBM cards, one card to each weather input point. This process takes as little as 1 hr, depending on the complexity of the wind-flow patterns. Since the prog charts are received 4 to 5 hr prior to the beginning of their 6 hr period of validity, the weather data may be processed and entered into the computer memory in sufficient time for the development of flight plans for even those flights departing at the very beginning of the valid period of the forecast. To insure a high degree of accuracy, the weather data are sight-verified before being fed into the computer. An additional editing process, however, is programed for the computer as the cards are read and entered into core storage. Any illogical or unusual values, such as wind directions from greater than 360°, or abnormal temperatures or wind velocities, are detected and returned for correction.

On completion of the analysis, punching, and read-in of the weather data, we have achieved, essentially, a three-dimensional model of the atmosphere in the core storage area of the computer. From the weather elements in storage, the computer program is able to derive a wind direction and velocity, a wind component, and a temperature for any altitude between 18,300 ft (500 mb) and 44,600 ft (153 mb) for any airway segment in the North America-Europe airways structure, and for any over-ocean segment in the North Atlantic.

The extrapolations and interpolations of data between the basic "prog" levels required to develop a wind and temperature at a specific altitude become somewhat complicated, especially if the tropopause lies through the layer being considered. In day-to-day operation, these factors are time consuming and a continual source of small errors when the calculations must be done by hand. However, with a three-dimensional model of the forecast data transcribed directly into core storage from the "prog" charts, and all altitude adjusting calculations made internally by the computer, the specific wind and temperature values are developed with unmatched speed and precision.

Minimum Time Track

Almost all airlines operating the North Atlantic make an attempt to select a best track for flight planning. For eastbound flights this selection is normally made from the USWB prog charts at the 300-mb level for jets, and the 500-mb level for turboprops, and possibly as low as the 700-mb level for piston aircraft operations. The basic objective, of course, is to determine the path that requires flying the shortest airmiles, or least time, when considering the wind-flow pattern that is forecast to exist. It is only rarely that the shortest ground mileage, without regard to wind, or the route of strongest wind assist, without regard to mileage, will produce this minimum time track. Some optimum combination of wind and mileage will more likely result in the shortest airmile distance, or the least time.

The present method generally in use by the airlines for the determination of minimum time tracks in long-range overwater flying, is a graphical system based on a report published by KLM in 1953. There is a long history of attempts to solve the general problem of defining the lease time path through a flowing medium, which will connect two fixed points. An empiric method for the construction of the most favorable routes for sailing ships was devised in the nineteenth century. In 1931, the problem was worked out mathematically in the navigation equation of Zermelo. Other theorists, at about the same time, related this problem to the propagation of light in a variable medium. The KLM paper was an extension of earlier theories and gave a practical solution useful in aerial navigation. The results obtainable from such a technique, however, are always subject to the variations in skill and judgment of the individual flight planner, and to the time and effort applied to the solution of the problem.

Fig. 2 General view of computer flight planning center showing IBM 1620 data processing system and weather data facsimile and teletype units.

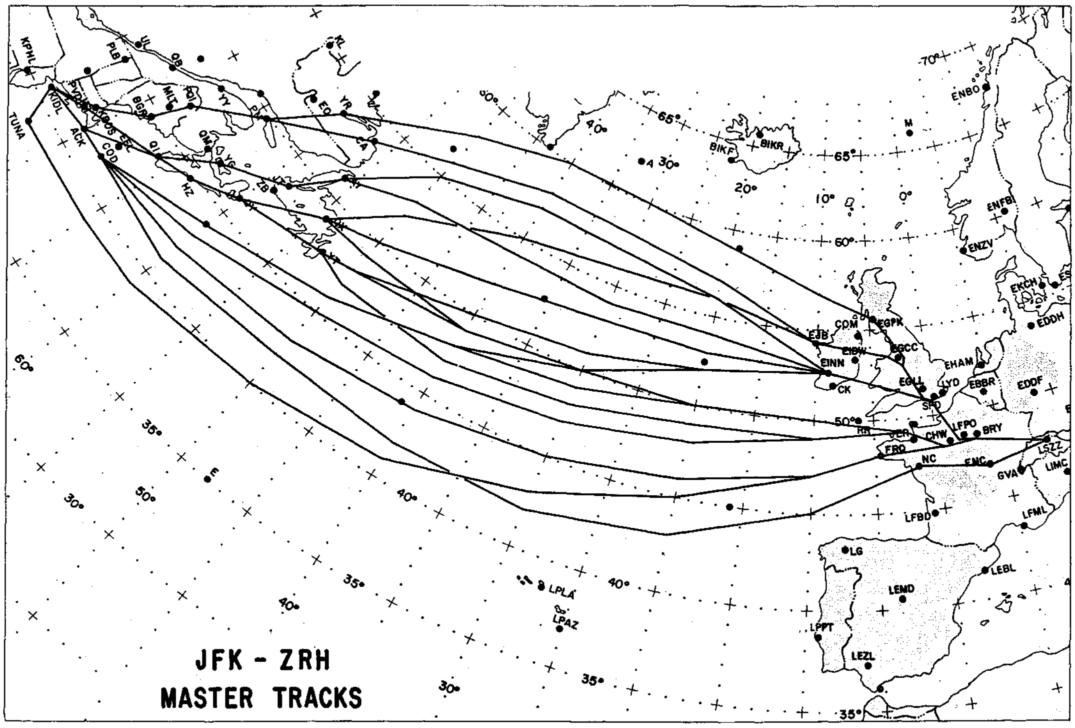

Fig. 3 Layout of typical "master track" set used in minimum time track selection process.

Over the North Atlantic there are restrictions on the number of routes that may be flown, imposed by air traffic control requirements, even in the over-ocean areas off of the domestic airways. Yet, there are literally thousands of different routes available which may be selected to take maximum advantage of the prevailing weather conditions. ATC requirements generally restrict the routing of aircraft to specific airways over the continental areas out to the specified "gateways," or entry and exit points to the ocean areas. In the over-ocean areas, off the specified airways, there is presently a requirement that each 10° meridian be crossed at a whole degree of latitude.

One of the limitations of the present graphical system is the requirement to "adjust" the minimum time track determined by the wind-flow pattern. After the "best" path is laid out on the weather map, the flight planner is required to make a judgment on how it should be adjusted to meet the requirements of the airways and the oceanic crossing points. Since these adjustments generally change the track headings and distance, he no longer knows whether or not the adjusted track is still the minimum time route. In the computer track selection system, since usuable tracks are analyzed at the outset, no adjusting of the selected track is necessary. The track selection is accomplished with full consideration of all the operational limitations imposed by the airways and longitudinal crossing points in the over-ocean areas. The track that is selected, then, is the fastest operational track for any given forecast wind pattern.

Computer Track Selection

The computer multiple track comparison and selection is accomplished in a two-pass system. In the first pass, a set of 15 to 20 empirically established "master tracks" between the desired flight origin and destination are compared under the conditions of the three-dimensional weather model stored in the computer (Fig. 3). These master tracks generally cover the extreme limits of latitudinal variation that may be expected in routings between the two terminals. They have various orientations with the different "gateways" from the North American airways to the ocean area and from the ocean area to the European airways. At this point the computer is programed to make its selections on the basis of time comparisons. The calculations of flight time on each of the tracks compared is based on an appropriate air speed and flight level, which are generally 475 knots and 33,000 ft for eastbound and 35,000 ft for westbound operation of jet aircraft. These values may be varied as required to fit the specific needs of any given operation, including the use of multiple flight level profiles. Another advantage of the computer system over the present graphical method is that the minimum time track constructed on the 300-mb weather chart (30,100 ft) is not selected for an operational flight level, nor does this two-dimensional analysis provide accountability for change of wind velocities with change of altitude. Experience has shown that the minimum time track for 37,000 ft may be substantially different than the one chosen for 33,000 ft, especially in areas where the tropopause has a pronounced slope and vertical wind shear is large.

The search for the minimum time track from among the "master tracks" examines only a limited number of the operational possibilities. The first pass merely narrows the field for a more detailed comparison and selection of the final "planning track" in the second pass.

In the second pass of the track selection process, the program analyzes all operationally likely track possibilities in a wide band along each of the two master tracks selected in the first pass. These possibilities may include several "gateways" on each side of the ocean (Fig. 4).

Track selection is a dynamic process. At each step in the analysis the computer extracts the appropriate wind data from the three-dimensional weather model. The results of about 700 alternative route possibilities are calculated and compared. The process continues until a sequence of flight segments to the destination has been selected which gives the fastest time.

Output of the computer's final track selection is in two forms. First the airway check points and the ocean coordinates that completely define the track are typed out on the computer's typewriter. At this point the track selections are made available to the airline dispatcher for examination against such factors as military airspace blockage that may make the selection impractical or forecast turbulence that may make the selection undesirable. If necessary, new track selections are made, with the undesirable or unusable areas eliminated from the selection process. Still another advantage of the computer system over the present graphical method is the following: when the best time track passes through an area on the map, which is not usable, the computer has the ability to reoptimize or select the best of what remains, a process that is impractical with the present graphical method.

The second form of output for the selected best track data is in IBM cards. Here the track is more completely defined in terms of headings and distances between all of the airway check points and ocean coordinates. The track data are now available for use in computing detailed flight plans for any given aircraft and operating procedure on the selected route.

As each weather model is developed in the computer, track selection is completed for all routes anticipated for operation during the validity period of the weather model. These data are then temporarily stored for subsequent combination with last minute aircraft and weight data for each selected flight just prior to departure.

Flight Planning Program

The CFPS is designed to handle a wide variety of aircraft types, planning techniques, and data requirements. The program is developed in segments, with independent "logic modules" used wherever possible. This approach allows rapid changing of any of the separate computing routines as required by the variations of aircraft, planning or output requirements, without affecting the remainder of the program. The flight planning program has the following four main routines: the central control, weather data, main line, and output forematter. The central control routine, as its name implies, maintains control of the program. This routine begins by reading and interpreting plan data input cards. It checks all parts of the program in the computer's magnetic core storage to make sure they are correct for the airline specified. The central control routine also determines which of the stored aircraft performance data will be used in computation.

Nine equations are required in computer storage to provide for calculations of a full gamut of performance information for each aircraft type, including climb time, climb fuel, climb distance, altitude capability, cruising air speed, cruising fuel flow, descent time, descent fuel, and descent distance.

For each aircraft type, a set of coefficients must be developed for each of the nine equations. A multiregression analysis program from the IBM program library has been used successfully for this purpose. To date, the jet aircraft of five international operators have been "fitted" by this process, with very satisfactory results. They include 707's and DC-8's and both straight jet and fan engines.

With the flight planning conditions thus "set up," the program branches to the weather data routine for assembly of wind component and temperature data on the tracks to be used in the flight plan calculation. As the next step, the central control directs the sequence of computations through the main line routine for the calculation of detailed flight plans. This step will be repeated until a complete plan is computed for every route and altitude requested. After all required altitudes on each specified route have been computed, the results are then examined. If this examination shows that none of the plans computed meets the objectives of the flight, additional calculations may be automatically initiated at revised weights, or at alternative cruising techniques.

The central control routine then compares the results of the time, fuel, and cost calculations for all usable flight plans and selects the optimum plan meeting the criteria established for the flight. Control of the program then branches to the appropriate output routine where a detailed format of the optimum plan is prepared with summary data of the other altitude and routes that have been examined. These data are then punched into IBM cards as the final output of the computation process. Once the cards are punched, the central control routine is ready to start over again on the next series of plans.

Plan Data Input

To meet the North Atlantic planning requirements of all operators, a wide scope of operating variables may be specified for each flight in the airline plan data input. These include

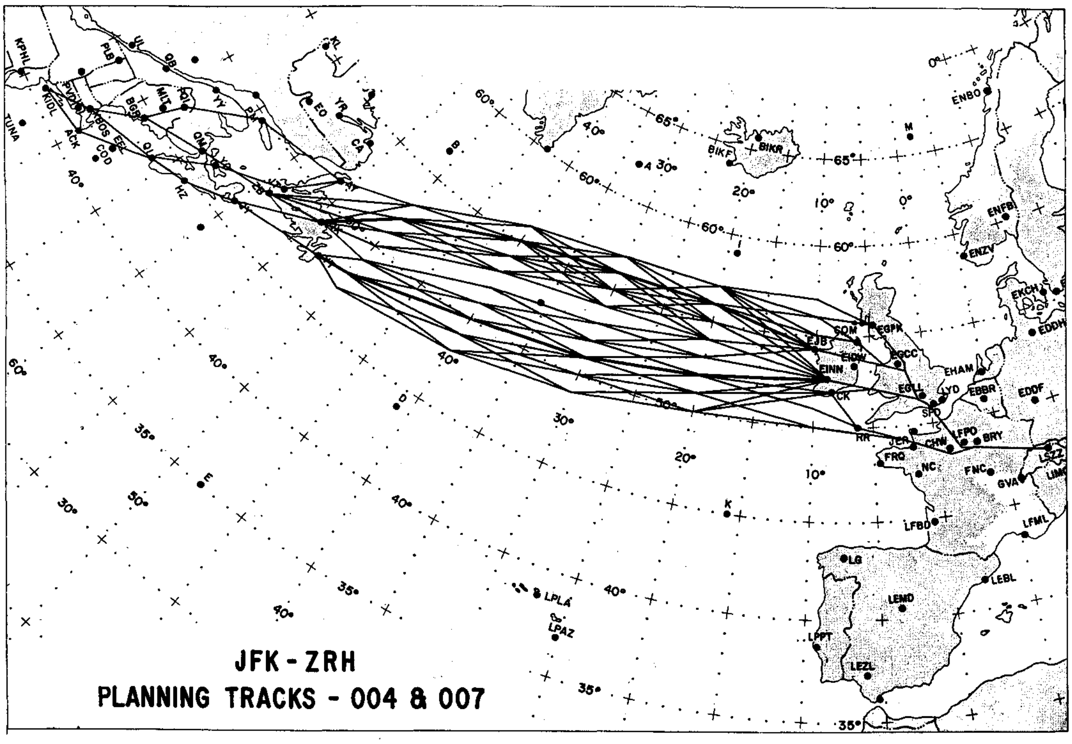

Fig. 4 Layout of typical "planning track" sets used to define the operational minimum time track.

the following: 1) airline (aircraft type); 2) flight number (estimated time of departure, origin and destination, elevation 1 and elevation 2, scheduled trip time, select option, cruise type); 3) maximum takeoff weight; 4) taxi fuel; 5) fuel specific gravity; 6) landing weight (dry tank weight + reserve or operating weight empty + payload + reserve); 7) alternate airport(s); 8) aircraft registration number; and 9) captain's name.

All of the forementioned variables need not be specified for every flight. Some items, such as captain's name, aircraft registration, and alternate airports are not processed in any way, but are only included so that they will be identified on the final printout of the computed plan. Flight number alone may be used to specify the six items listed under it. These items may then only be entered when they are off schedule or nonstandard.

The series of computations required for the development of each flight plan is initiated by the introduction of the airline plan data on a single IBM card. The plan data are combined with track information previously developed and read into the computer system. At this point a completely versatile system is retained by allowing the flight plan computations to be made on any track selected within the limits of the three-dimensional weather model. Normally computations would be completed on the minimum time route, and alternate routes determined in the track selection process, however, any other routes specified may be entered for analysis and comparison.

Full versatility is also retained in the specification of flight altitudes to be examined. Under program control, all planning altitudes appropriate to the direction of flight (29,000, 33,000, 37,000 eastbound) may be examined. Step climbs will be computed as required to take full accountability of the performance limitations of the aircraft. This may result in the development of a complete flight plan on three different altitude profiles for each selected route. Optional profile control may be used to specify a nonstandard flight level for planning or to impose a ceiling or a minimum altitude along certain segments of a route for military blockage compliance. Even when the profile is specified, however, there will still be full accountability for aircraft performance limitations. Results will only be produced which are compatible with the weight and temperature limitations on altitude performance.

An editing process is also used when plan and track data are read into the computer. This process checks for the presence and proper sequencing of all the necessary planning data. It also checks that all track data used are appropriate to the origin and destinations specified in the plan data. A further check of the suitability of all planning data is made by comparing the estimated time of departure on the plan data input to guarantee that it is within the validity period of the weather model in storage. Error messages will be automatically produced on the computer typewriter to advise of any discrepancies found during the editing process.

Flight Plan Computation

Computations of the detailed plan for each track and altitude start at the destination and at the desired landing weight. The airline will specify the landing weight for each flight, or the components of the landing weight such as dry tank weight plus required fuel reserve, or in more detail, operating weight empty plus desired payload plus reserve. Descent data are first calculated to determine the time, fuel, and distance required during this portion of the flight. Successive calculations are then made for each cruise segment of the flight along the route back toward the point of origin. Finally, a climb zone is calculated, and the total time and fuel requirements for the flight are determined. During this process, the altitude capability of the aircraft is being checked constantly to make sure the airplane can cruise at the altitude in question. If it cannot, then the planning altitude is reduced to the next appropriate flight level for the direction involved.

The weight of fuel burnout required for each flight is added to the desired landing weight to determine the resulting takeoff weight. This value is then compared with the allowable takeoff gross weight to insure that the plan is within the limitations of the input data. The maximum takeoff gross weight specified for the flight may be limited by runway length, climb requirement, noise abatement, or structural limitation of the aircraft as appropriate for the flight, and is specified for each flight by the airline.

The program also adds the weight of fuel burnout for the flight to the required fuel reserve to get total fuel requirement. This value is then checked against the tankage capacity of the airplane to determine that the flight plan is within limitations. Fuel tankage capacity is the product of tank volume (a stored program constant) and the fuel density value that is input on the plan data and may vary from flight to flight).

The specification of cruising type on the plan data input is used to determine the coefficients that will be applied during the calculation of the plan. If after exploring all the usable track and altitude alternatives a usable plan is not produced, then other cruising techniques may be programed for examination at the option of each airline. One planning policy commonly used by North Atlantic carriers is to consider cruising at constant Mach 0.82 speed as "standard" or "normal" technique. Long-range cruising, (i.e., a speed schedule variable with airplane gross weight to produce approximately maximum miles per pound of fuel consumed) may then be employed if Mach 0.82 operation will not allow the desired payload.

The program accommodates the option to input scheduled time for each flight, since it may be a desirable basis for the selection of optimum flight plans. The relation of computed flight time of a given plan to scheduled time may also have a bearing on the cost formula useful in assessing the variation between alternatives to select plans based on minimum operating costs.

The flight direction (east or west) is input or pre-established for each flight number. This information is important to establish the flight levels appropriate for planning. It also controls the manner in which the program interprets the weather model.

All flight planning calculations are based on the assumption of normal climb and descent from sea level. In the event that either the origin or destination airport is sufficiently above sea level to warrant climb or descent time, fuel, or distance corrections, the airport elevation may be entered as plan data input.

The greatest value of the CFPS versatility is realized through the select option. The select option may be plan data input for each flight or predetermined for each flight number. It establishes the basis on which the multiple-plan computations for each flight will be compared; it directs the selection of the plan most closely satisfying the objectives of the specific flight. It allows this plan to be produced in complete detail as the end result of the computer flight planning process. A wide variety of select options may be programed for the system. These may include maximum payload, i.e., least fuel burnout, lowest direct operating cost (DOC), fastest flight time, or combinations, such as lowest DOC within scheduled time, or fastest flight that will carry the desired load.

Flight Plan Output and Delivery

The end product of the weather analysis, track selection, and flight plan computations made by the CFPS is a teletype message delivered to the operations office of each user airline. Each message will contain the majority of information needed by the pilots, dispatchers, and other operations personnel for the preparation and conduct of the flight. A typical message includes most, or all, of the data shown (Table 1):

Line 1: Message priority, address showing coded city/airport, office and airline to which message is sent.

Line 2: Date/time group and coded address of message origin.

Line 3: Airline/flight number, date, origin-destination of flight, estimated time of departure, planned landing weight, planned fuel over destination (reserve), and alternate airport(s) designated for the flight.

Line 4: Takeoff gross weight computed for the flight, cruising speed schedule used in the plan, the minimum takeoff fuel required (burnout + maneuver + reserve), the calculated flight plan time, the direct cost of operation of the flight based on the plan (when cost data are specified by the airline), and the type aircraft for which the plan is calculated.

Lines 5–20: Detailed flight plan data are presented for each segment between specified check points (positions) along the route, from point of origin through top of climb (TOC) at land stations and ocean coordinates to top of descent (TOD) and destination. Segment ground distance, flight level (altitude), average forecast temperature (minus signs omitted), average true air speed, average forecast wind component, resulting average ground speed, time required to fly each segment, accumulated time from takeoff, fuel burned in each segment, and accumulated fuel burned.

Line 21: Total ground distance of route and over-all average forecast wind component. (P = plus/tailwind, M = minus/headwind.) Detailed data are provided for the selected "optimum" plan. Summary data are provided for a large number of selected alternative plans.

Line 22: Total time, fuel and operating cost of flying planned route at flight level 330 (33,000 ft) for entire trip instead of climbing to 37,000 ft at 49/40 as in "optimum" plan.

Line 23: Total time, fuel, and cost on planned route at 29,000 ft.

Lines 24–26: Total time, fuel, and cost of flying "great circle" route at 37,000, 33,000, and 29,000 ft, respectively. Computations include accountability for performance limitations and step climbs as required to reach final cruise altitudes listed.

Line 27: Listing of check points and ocean coordinates (643 = 43°N/60°W) of alternative route on which plans were also computed.

Table 1 Sample computer flight plan

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1.   QU IDLOWSR
2.   .282018 NYCWWYY
      FLIGHT   DATE    FROM TO   ETD     LWT    FOD  ALTN1 ALTN2
3.   SR  801  2/28/64  IDL ZRH  2250Z   195.6   19.2  LSGG
      TOGW    CRUISE  MIN TOF   FLTM    COST    A/C
4.   278.7     M 82    102.3     6:49   $4198  DC8-F
     PSN    SEG  FL  AVG  AVG   AVG  AVG     TIME        FUEL
           DIST      TMP  TAS  COMP   GS   SEG   ACC   SEG  ACC
5.   IDL         000                                        0000
     TOC    172  330  24  364  P060  424  0:24  0:24   097  0097
     ACK    012  330  53  474  P130  604  0:02  0:26   002  0099
     QI     233  330  54  473  P133  606  0:23  0:49   053  0152
     HZ     133  330  56  471  P132  603  0:13  1:02   029  0181
     QY     160  330  57  470  P127  597  0:16  1:18   035  0216
     YT     311  330  56  471  P098  569  0:32  1:50   068  0284
     48/50  115  330  55  472  P063  535  0:13  2:03   027  0311
     49/40  401  330  54  473  P037  510  0:47  2:50   101  0412
     50/30  394  370  55  472  P038  510  0:47  3:37   091  0503
     50/20  385  370  56  471  P056  527  0:43  4:20   084  0587
     50/10  385  370  51  476  P046  522  0:45  5:05   081  0668
     JER    314  370  49  479  P020  499  0:37  5:42   066  0734
     BRY    222  370  52  475  P006  481  0:28  6:10   049  0783
     TOD    092  370  53  474  P012  486  0:11  6:21   020  0803
20.  ZRH    138  000  24  369  P006  375  0:28  6:49   028  0831
21.  TOTAL 3467      AVG COMP P057
     SUMMARY      TIME   FUEL   COST
22.  FL 330       6:47   085.1  $4210
23.  FL 290       6:46   093.7  $4357
24.  GC TRK 370   7:03   086.7  $4346
25.  GC TRK 330   7:03   088.9  $4385
26.  GC TRK 290   7:02   097.2  $4525
     ALTN RT
27.   IDL COD 643 545 447 349 250 150 JER BRY ZRH
28.  FL 370       6:50   083.3  $4200
29.  FL 330       6:48   085.3  $4221
30.  FL 290       6:47   093.9  $4365
     AERO PERFORMANCE INC
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Lines 28–30: Total time, fuel, and cost of flying alternative routing at 37,000, 33,000, and 29,000 ft, respectively.

The service is designed to allow each operator to specify the format in which the messages will be delivered. The only restriction on formating is the teletype system limitation of 68 characters per line. The computer assembles and formats all the flight planning data under program control and causes an IBM card to be punched for each line of teletype data in the message.

The designation of the airline on the plan data input card controls the addressing of the teletype message, so that there is no opportunity for misdirection of plans between users. The message may also be programed for multiple addressing in the event that the flight plans are required as information at several stations.

The only information not available to the computer system for completion of the plan is the time of day necessary to supply a date/time group in the addressing of the teletype message, since the 1620 does not have an internal clock. This requirement is handled by programing, where at the end of each series of plan computations the computer will stop, type out a request for the operator to insert the Greenwich time, and when this is done, complete the formating and outputting of the final plan message.

The punch card output for each flight plan message is then transferred to the telegraphic card reader. Here the cards are "read" automatically into the teletype circuit for delivery to the respective airline. The present system feeds the plan messages directly to the airline's communication center or into the switching center of Aeronautical Radio, Inc., where they are distributed to the various airlines' communications centers or operations offices. A teletype printer is used in the flight planning center to monitor the output of all transmissions to provide "hard copy" of each flight plan.

Service Experience

Final development of the computer flight planning program and installation of facilities took place during the fall of 1963 and the early part of 1964. Service testing under actual airline operating conditions was begun with Swissair on February 17, 1964. Previous to this time, Swissair management and technical personnel cooperated in the system development and check-out steps leading to its activation.

Testing and trial applications of the system have since been conducted for seven airlines. Starting July 1, 1964, full-time daily service has been provided for North Atlantic flights of Swissair, Scandinavian Airlines System, KLM Royal Dutch Airlines, Seaboard World, and Pan American World Airways. Additional carriers continue to evaluate the system for both eastbound and westbound flights.

Comparative testing against manual track selection and flight planning procedures has demonstrated average flight time savings of 5 min and fuel savings of 1000 lb in eastbound operations and over 15 min per flight for limited seasonal testing in westbound operations. These tests have also demonstrated the ability of the system to accommodate variations in routing, air traffic control, performance, and procedural requirements unique to each operator. They have also demonstrated the capacity to provide a wide scope of information relating to the operating potential of each flight in the form of data related to alternatives in routes, altitudes, and cruising techniques.

Operational experience to date has highlighted one outstanding requirement of the system, versatility. So far, in adapting the service to five different airlines, API has been required to develop five substantially different variations to the main program. No two carriers have been found to use the identical planning procedures, cruising techniques, or output format. And, although, among four of the carriers there are three basic aircraft types, the JT-4 powered DC-8 and 707 and the fan powered DC-8, we have found it necessary to provide seven sets of performance equations, since no two

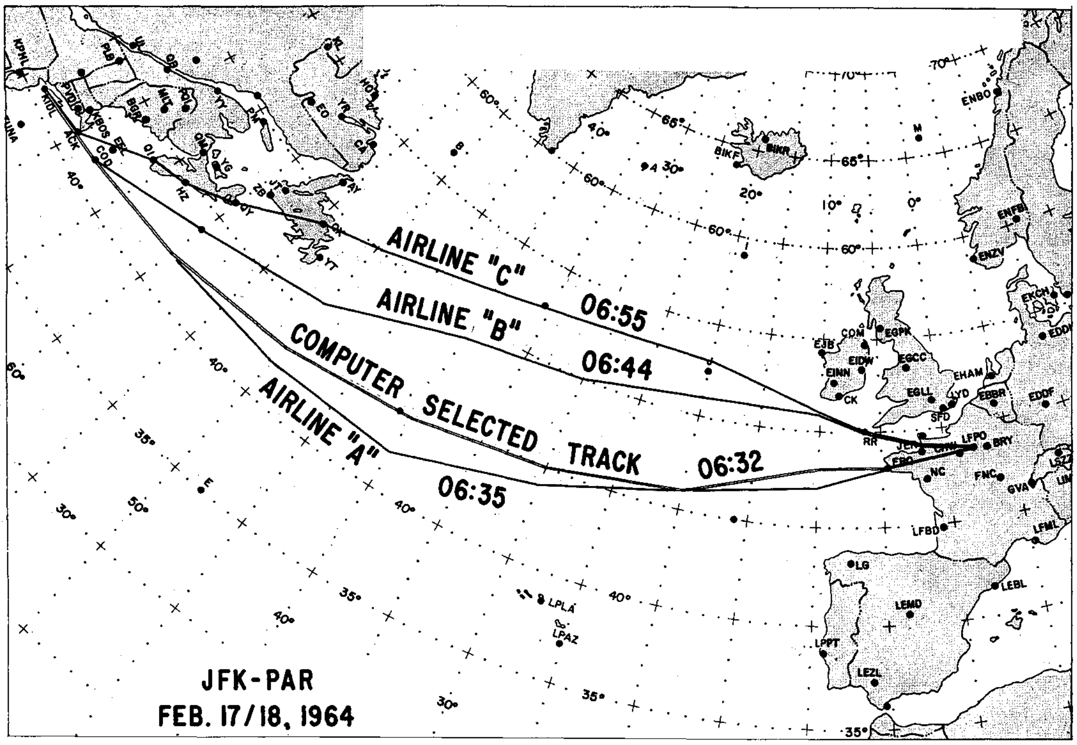

Fig. 5 Routes planned for flights New York–Paris (eastbound) for jet aircraft departing within 30-min period, February 17, 1964.

airlines publish the identical performance data, even for the same model aircraft. A similar requirement for versatility exists in the development of track data. Each carrier has a different table of mileages that must be used in computing flight plans between the same points. There are also differences in the airway routings that will be used to the ocean gateways. Some airlines will use a route that others may consider nonauthorized. Differences exist in the required check points for which each airline will want flight data summarized on the plan. These factors require an extensive library of track information to provide the versatility necessary to handle these requirements for all the airlines.

The program variations used to accommodate the diversity of performance requirements among the airlines also point up the need for versatility. The preferred type of cruising technique with two of the airlines is at constant air speed of Mach 0.82. With another airline, it is also at constant speed, but with a Mach number that varies with altitude. For still another airline, it is a constant speed of Mach 0.80 for one type aircraft and at a variable speed schedule approaching maximum fuel economy for another type aircraft. Three of the four airlines employ so-called "long-range" cruising when maximum fuel economy is required. Two of the four airlines employ "high-speed" cruising for use when it is desirable to make up time. In one case this is done at maximum cruise thrust, and in another, at constant speed of Mach 0.83.

The concept of developing the CFPS to adapt to each airline situation, rather than require changes of the airline techniques for use of the system, was established in the early stages of the research work leading to this project. The concept has proved to be a sound one. An airline's conversion to use of computer produced flight plans requires only minor procedural changes, since the plans are substantially identical to those that dispatchers and pilots have been trained to use on the North Atlantic and on other routes.

Experience in the track selection program has emphasized the computer advantages mentioned earlier, of using only operational tracks and altitudes for selection of the best overall route. An interesting example of track selection in relation to the interrelated problems of technical precision, air traffic control requirements, and operating economy, was found on the first night of active service testing of the system. On February 17, 1964 (February 18, Greenwich), the flight plans filed for the many flights leaving North America that same evening for Europe were examined for comparison with the computer's selections. Among these there were three trips that filed flight plans to Paris on very widely divergent tracks, although the departure times were all within 30 min of each other (Fig. 5).

Analysis of this case has shown that, for aircraft of the same weight and performance, an additional 20 min and approximately 4000 lb more fuel was required on the most northerly track. The differences shown may result from the planner's attempts to "second-guess" the meteorologist by attributing a greater reliability to his forecast on one route than on another. They may also result from the individual planner's attempt to "out-guess" the air traffic control situation by selecting a route that may not be the best, but in his judgment would offer the greatest opportunities for a satisfactory clearance from ATC. In either event, the resulting planning standard will reflect the differences in skill, experience, and judgment of the individual flight planner. Comparisons of actual flight results with computer and manual flight plans have shown no benefits of this application of "judgment" to justify the flight time and fuel penalties generally involved in such procedures.

Further consideration of this same example raises the question of whether a more precise track selection system would not aggravate the air traffic control problem by causing all flights to file for the same route. Experience to date indicates that the reverse will be true with a wider application of computer flight planning. It should be noted that, on February 17 (the example referred to previously), airline B planned three separate trips on the track shown, branching off to separate destinations in the latter part of the flight. Airline C did the same for five trips on the same track. On the other hand, the computer shows a remarkable precision in selecting the optimum track to each destination (Fig. 6).

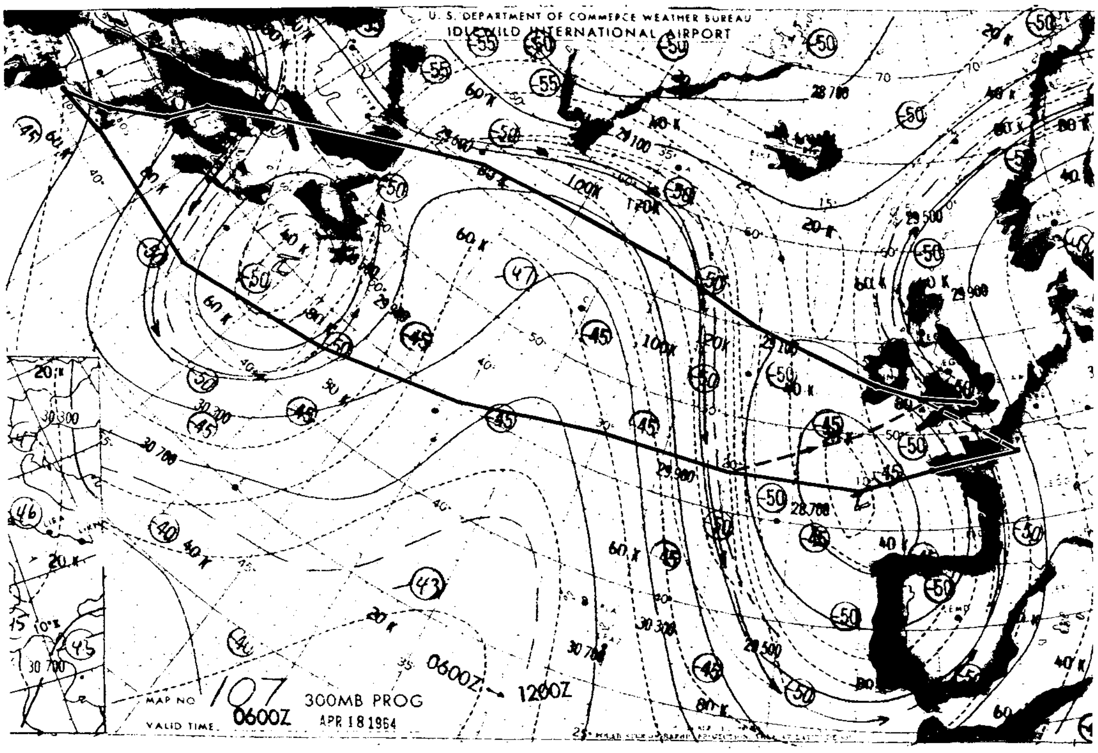

Fig. 6 Computer selected minimum time tracks for eastbound flights New York–London, New York–Paris, April 17, 1965 (April 18, Greenwich).

In this case, which occurred on April 17, there is wide divergence in the best track selected for two destinations, even though they are only 200 miles apart. A comparison of plans on these tracks shows that, if the technique used by airlines B and C in the previous example were employed here, and the northerly track (minimum time track to London) had been determined first and was then also used to Paris by branching off, or conversely, the southerly track (minimum time track to Paris) was used to London by branching off, the penalty in each case would be approximately 12 min flight time and 2000 lb of fuel used.

A further examination of the computer track selections from the April 17 weather model for a larger number of routes, will illustrate how the best tracks will spread out when precisely selected for each destination (Fig. 7). This particular character of the true minimum time track is of interest in

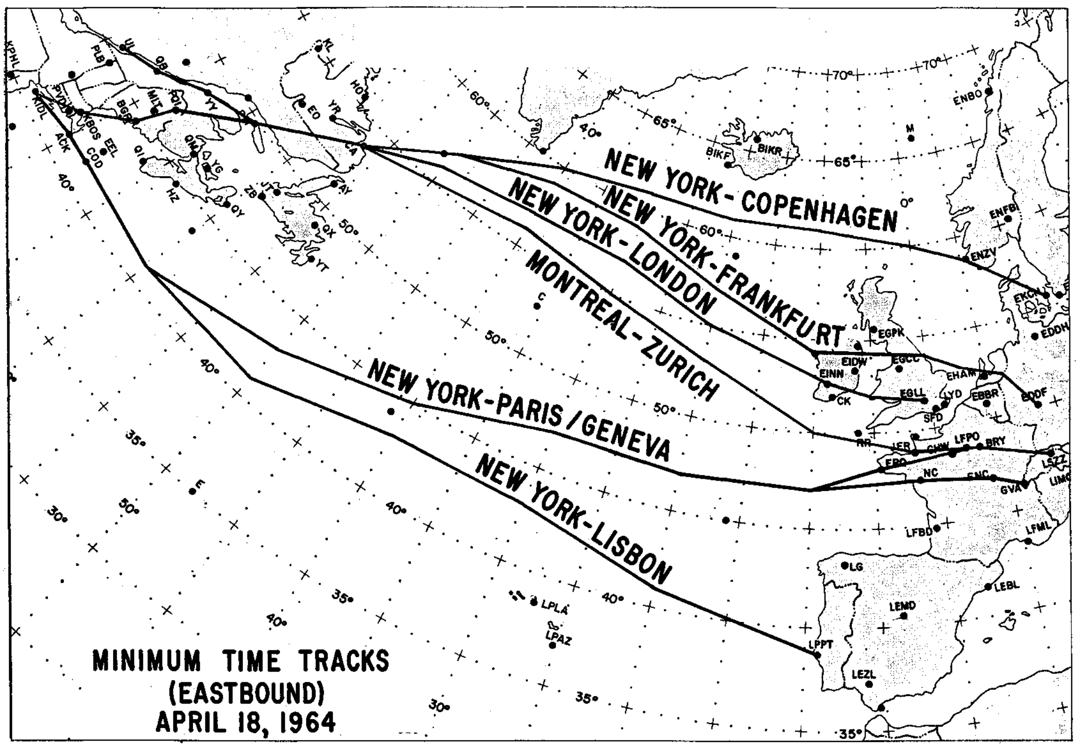

Fig. 7 Operational minimum time tracks for selected eastbound flights, April 17, 1964 (April 18, Greenwich).

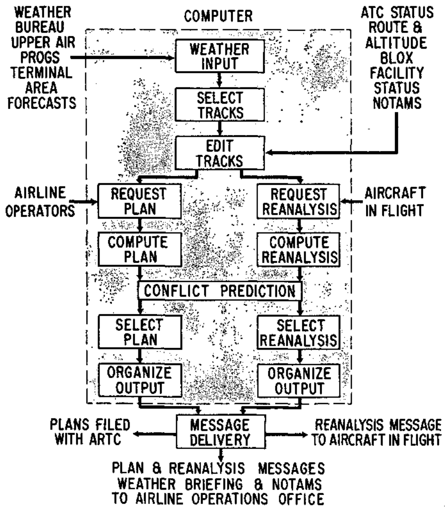

Fig. 8 Computer flight planning future operating sequence.

relation to the present studies to bring about an "organized" route structure in the North Atlantic. Under one system of organization generally referred to as the "jet reference scheme," the air traffic control agency selects on each day the track that corresponds to the "minimum time track." All aircraft will be permitted to fly only on this track or parallel tracks separated from it by at least 2° of latitude (120 miles). It can be seen from the example, that since there is no single minimum time track for the North Atlantic, even such a system that envisions retaining the versatility of free trackage will still impose substantial operating penalties.

Future Development

As the volume of international air traffic continues to grow, it will be desirable, if not essential, to automate all operations data analysis and planning to keep pace with the advances in technology in navigation, communications, and flight equipment. A major activity of the airline dispatch/operations control function, which has data handling requirements similar to those for preflight planning, is in the provision of reanalysis service. It is a common practice of the international airlines to provide the latest weather analysis to inbound aircraft in flight at about the midpoint of each trip. This information is used by the pilots in determining a requirement for changes to the routes, altitudes, or operating speed schedule of the original flight plan in order to best accommodate the changing conditions. Similar principles of analysis are necessary to produce an optimum plan from some point in flight as are required to prepare an optimum preflight plan. It can be seen that the CFPS may also become a valuable tool to expand the capability of dispatchers and pilots in the rapid handling of large volumes of operating data for reanalysis as well as in preflight planning (Fig. 8).

There are vast amounts of constantly changing information which, although not directly processed in the computation of flight plans, are of great importance in the planning and conduct of the actual operation. The types of information, which must be analyzed in detail by dispatchers and pilots prior to each flight, are the status of air-route traffic control, military airspace reservations, status of navigation facilities, and significant weather, both enroute and at the terminals. Under the proper impetus, expansion of the CFPS can be envisioned to allow these categories of information to be assimilated constantly. With such an adjunct to the system, a properly edited summary of all pertinent operating information and notices to airmen (NOTAMS) could be automatically provided as a supplement to each computed flight plan.

The flight plans prepared for each aircraft operating the North Atlantic today, including those prepared by the CFPS, must be filed with the appropriate Air Route Traffic Control Center (ARTCC) prior to the departure of each flight. The many operations offices involved in this function all prepare manually, teletype messages for filing with ARTCC. When the messages are received by these agencies, they may again be manually processed for input to the air traffic control computer. There is an opportunity for the CFPS to increase the efficiency of this function by more fully automating these data handling requirements.

The present work of the USWB at the Numerical Weather Center at Suitland, Md., in automated processing of meteorological data, gives promise of further improvements in speed and reliability of weather forecasting for airline flight planning. To provide a computer flight planning system free of the restrictions for manual preparation of weather data input would offer the prospect of even greater versatility and the possibility for widely expanded area coverage. At some time in the future, it is anticipated that the CFPS will be developed to operate on direct automated input of computer produced weather prognostications prepared by the USWB.

The long-range potential for a centralized computer flight planning service for the air transport industry is essentially unlimited. It is possible to envision communications systems that allow a dispatcher/operations controller to interrogate the flight planning computer from a remote location (similar to the traffic agents use of an automated reservations system) and cause an optimum flight plan (plus all pertinent operating information) to be immediately generated and returned to him for use just prior to each departure. At the same time, this plan could be filed automatically with the ARTCC. A similar type function can be envisioned for aircraft in flight where the pilot may communicate with the CFPC and immediately receive a reanalysis message specifying the optimum course of action for the remainder of his flight.

It may also be desirable to program the computer produced flight plan data for direct input to each aircraft's navigation and flight control equipment. The plan will specify the desired climb, cruise and descent profiles, the desired track to be flown, and other operating requirements of the flight for use as datum information for the operation of the airborne navigation and control devices to automatically guide the aircraft throughout its flight.