SYSTEM TOOL FOR AIRCRAFT ROUTING

By

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ABSTRACT

Operations Planning at CP Air is responsible for keeping an up-to-date visual representation of the aircraft routings for the current schedule period and co-ordinating subsequent changes. Examples of changes are requests for extra usage such as charters or extra sections, changes to the maintenance schedule, and unforeseen circumstances.

The present approach is a manual charting method used in the same or similar form by many airlines as well as at CP Air. This manual process is long and tedious and even minor changes can cause much work to keep the charts up-to-date and everyone informed.

What is needed is an automated system that will present the information produced on the charts in the most useable manner plus the ability to make changes so that the resulting information can be more effectively used than with the present manual method. The approach taken is the development of a Decision Support tool that will allow Operations Planning to make decisions based on their knowledge and experience. This solution is a starting point in an area at CP Air that has long needed some automation.

The system has been developed on the Virtual Machine operating system using IBM 3279 equipment for its color capabilities, and it is currently in the stages of system testing and user-training.

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SYSTEM TOOL FOR AIRCRAFT ROUTING

CHAPTER 1

INTRODUCTION

1.1 Background on Scheduling

The major concern of an airline is to plan and operate an aircraft schedule that will best serve the public, yield the greatest profits and maximize the utilization of its equipment. The process from schedule planning to operation in general will involve the following aspects:

1. Schedule Construction

This is the preparation of a working schedule of flights so that passenger demand is best satisfied. Typical questions that must be answered in this preparation are:

a. Market Planning

- What cities should be served?

b. Frequency Planning

- What is the design of the route structure?
- How often should these routes be flown?
- What aircraft type and seat configuration is best for these flights?

c. Time-of-Day Planning

- What departure times should be assigned to these

flights?

d. Aircraft Rotations (flight patterns that could be operated by the aircraft)

- Can this schedule be operated with the given fleet?

- What is the minimal number of aircraft needed to operate the schedule?

2. Schedule Evaluation

This is the analysis of a given working schedule. Typical questions include:

a. What are the expected costs and revenues to be generated from operating this schedule?

b. Is it operationally feasible?

- Are there sufficient opportunities for maintenance?

- Are the times between flights sufficient to service the aircraft?

- Can crews be feasibly assigned?

c. Are there opportunities for extra flying?

d. Could the schedule be adjusted so that it required fewer aircraft?

e. How well can the schedule handle changes that will inevitably occur?

- Are there sufficient opportunities for aircraft exchanges to be performed? (places where aircraft could be rerouted)

In general, the development of the schedule is an

iterative process of schedule construction and evaluation.

3. Aircraft Routing

Once a final version of the schedule has been approved, aircraft tail numbers (all aircraft are uniquely numbered) are assigned to the flights. In general, this involves adjusting the aircraft rotations previously developed.

4. Dynamic Scheduling

Many changes to the plan occur during the life of the schedule. These changes can sometimes be handled quite easily, but also can have ramifications involving rescheduling of flights and aircraft throughout the period of the schedule. If rescheduling is required, then an attempt is made to return to the original plan as soon as possible. The following are examples of possible changes that might occur:

a. Requests for extra usage

- charters, extra sections, crew training, advertising requirements, etc.

b. Adjustments to maintenance schedule

- unexpected maintenance work, an aircraft late out of its check, or extreme variations in aircraft flying hours that could cause maintenance rescheduling

c. Emergency situations

- weather conditions, crew unavailability, or equipment failure

These changes can only be handled as they arise in schedule operation, and hence this area is referred to as "dynamic scheduling".

Etschmaier and Mathaisel (1984) give a concise and complete overview of the work that has been done in each of these areas. In summary their findings are:

1. The problem of aircraft scheduling does not have an analytical solution due to a changing environment, constraints that are dependent on circumstances and people, and a multi-criteria objective function that cannot be completely quantified.

2. The limitations of the computer and the versatility of the human mind in planning decisions in a changing environment have been recognized. Thus the "state-of-the-art" work is concentrating on developing an interface between man and machine so that both perform the tasks they are best suited for.

3. There are no systems in practical use that have found an optimal balance between the roles of human judgement and capabilities of the computer, and few that have any imbedded Operations Research models for optimization and simulation. The use of Operations Research has mostly been to help conceptualize and formalize the scheduling process.

The focus of this project is in the areas of aircraft routing and dynamic scheduling. The main purpose being to track the individual aircraft in order to be able to dynamically plan and respond to the changes that will occur during the life of the schedule. Etschmaier and Mathaisel (1984) report that no work specifically in this area has been published to date.

1.2 Situation at CP Air

At CP Air, several areas of Operations are responsible for managing the aircraft routings and any subsequent schedule changes. Maintenance Planning establishes the maintenance schedule and the routing of the narrow-body aircraft; Operations Planning routes the wide-body aircraft and co-ordinates all changes to the schedule beyond the next ten days of operation; and Operations Control handles all unforeseen circumstances during the next ten-day period.

Operations Planning is the key source of planned aircraft routings and the key co-ordinator of the decision-making process involving aircraft usage. The role of Operations Planning has been termed "Aircraft Cycling and Substitutions". Aircraft cycling involves routing the aircraft onto repeating patterns of flights. The main purpose of aircraft cycling is to efficiently satisfy the requirements of the schedule and maintenance. Often all the requirements cannot be met and aircraft substitutions are necessary. For a more detailed description of Operations Planning, see Appendix A.

The present approach to aircraft routing is a tried and proven method used in the same or similar form by many airlines as well as CP Air. It involves producing large charts that graphically portray the aircraft routings. However it is a manual system and therefore the process is long and tedious. The charts have to be drawn and the

schedule graphically displayed on it before the cycling begins.

The cycling requires numerous iterations in order to assess different routing patterns to satisfy maintenance requirements and other constraining situations. The aircraft are then routed according to the cycling pattern chosen, making adjustments where necessary. Subsequent changes to the schedule and routings cause the charts to become messy with all the erasures of lines and drawing of new ones.

The analysis of a range of alternatives can also be a long and tedious process. Some alternatives can be evaluated by modifying the permanent routings on the master sheets. More often, when a complex set of circumstances occurs involving several aircraft, it is necessary to reproduce the charts for the period of time required and experiment with difficult routings until a satisfactory solution is reached. This then has to be transferred to the master sheets and the old routing erased. Occasionally the solution will not satisfy all the cycling conditions and some further manipulation is required.

As well, a record of all the changes must be compiled and a flight order distributed to all the departments concerned, especially Maintenance Planning, Crew Scheduling and Payload Control (personnel who control passenger booking) when the changes have affected the maintenance plan, type of aircraft or the seat configuration.

The size of the fleet has now made it impossible to arrange all the aircraft on one sheet so cross referencing to a second sheet becomes difficult.

It is very apparent that there are heavy time and labor requirements to produce and update the aircraft utilization charts. Even minor changes could cause much work to keep the charts up to date and everyone informed. This is clearly an inefficient use of manpower. The present manual method does not adequately support the needs of the Operations Planning area.

What is needed is an automated system that will include the information produced on the charts plus the ability to make changes so that the resulting information can be more effectively used than with the present manual method.

CHAPTER 2

DECISION SUPPORT APPROACH

2.1 Decision Support Systems

A Decision Support System (DSS) is an interactive computer-based system that helps decision-makers utilize data and models to solve semi-structured problems.

Traditional programming techniques cannot be applied to these problems since in general they involve many qualitative constraints requiring human judgment. DSS tries to create a balance between these two factors of human judgment and ability of the computer. It focuses its attention on key decisions and tries to improve the effectiveness of the decision-making process.

Effectiveness lies in the ability to identify what information is needed in order to solve the problem and to present this in a clear and usable manner. The decision-maker must then be able to analyze a range of alternatives plus the consequences of each.

According to Keen and Morton (1978), DSS can be useful in a situation that involves some of the following characteristics:

"1. The existence of a large data base, so large that the manager has difficulty accessing and making conceptual

use of it.

2. The necessity of manipulation or computation in the process of arriving at a solution.

3. The existence of some time pressure, either for the final answer or for the process by which the decision is reached.

4. The necessity of judgment either to recognize or decide what constitutes the problem, or to create alternatives, or to choose a solution. The judgment may define the nature of the variables that are considered or the values that are put on the known variables."

A Decision Support System is tool-oriented rather than process-oriented and thus does not restrict the user to a pre-defined process, but rather allows him to develop his own methods for solving problems. Thus the system needs to be built with feedback from the user to ensure that the development is proceeding correctly. The approach is to implement an initial design and then after a short period of use, the system is evaluated and modified. This iterative design is repeated several times until a stable system is established.

Thus the development of a decision support tool can be viewed as a learning process (see Lembersky, 1984) for the user by which he discovers new levels of support for

decision-making.

2.2 System Objectives

The main objectives of this project are defined to be:

1. To implement a decision support system.

A DSS approach to the areas of aircraft routing and dynamic scheduling seems appropriate because of the following characteristics:

a. The existence of a large data base, with the need to reference, visualize and cross-reference information on aircraft routings.

b. The necessity of experimenting with complex routings until a satisfactory solution is reached.

c. The existence of some time pressure for answers, in particular the handling of emergency situations in Operations Control.

d. The existence of many constraints and objectives (some qualitative) that require human judgement to discern how to prioritize in a given situation. Typical constraints include:

i. Maintenance requirements

Aircraft must be brought in - for maintenance checks at the proper times, and the flying hours must be balanced.

ii. Operational Requirements

A typical operational requirement is the time

required to service an aircraft depending on the station.

iii. Route Restrictions

The label 'route restriction' is used to denote a broad class of requirements constraining certain aircraft to certain flights.

The most common route restriction is for aircraft to fly those flights that allow for its type and seat configuration. Certain routes also require aircraft with special characteristics such as maindeck baggage, bunks, or extended range (larger fuel tanks). There are often qualitative considerations where one aircraft is better suited than another.

In general, a flight is never split using two different aircraft since this is an inconvenience for the passengers and baggage handlers.

iv. Station (Airport) requirements

Station requirements refer to any considerations that are particular to a certain airport. An example of a station requirement is that Toronto airport is closed between midnight and 7:00 a.m. Another consideration could be the availability of fire prevention workers at the time of arrival at an airport.

v. Availability of a properly trained crew

Crews are trained for specific aircraft so an

aircraft substitution may require crew rescheduling. As well, there are limits to the hours the crew are required to work, so a crew would be entitled to "book-off" if the delay of a flight caused these limits to be exceeded.

These constraints are enforced as much as possible, however, no constraint is absolutely binding. For instance, aircraft can be substituted, bunks can be added, maintenance requirements have built-in leeway, aircraft can be serviced in less time if necessary, and special arrangements can be made for station requirements. There is a cost associated with violating any constraint and this cost is both monetary and qualitative in terms of passenger inconvenience. In any situation, an effort is made to minimize the passenger inconvenience. For this reason, human judgement is required to determine the best course of action.

These constraints must be balanced as often there is no "right" solution, but there are "better" solutions. Aircraft routing and dynamic changes rely on the experience of the planner in discerning which constraints have higher priority in a given situation. A computer program could not hope to replicate this experience. Thus a DSS would allow the planner to use his experience, and since it is tool-oriented rather than process-oriented it would allow a variety of planners to develop their own methods.

2. To implement a DS system that is easy to use.

Although the users have years of invaluable experience, they are non-technical people. It is important for them to become familiar with the computer and what it can do for them.

In order to develop an useful tool that the users will support, this system should:

- require a minimal knowledge of computers or computer languages
- use concepts familiar to them
- start small and build depending on their directives.

3. To focus on key aspects of the problem that will directly support the decision-making process. These have been defined to be:

a. Identification of downtime periods (idle time for the aircraft) in terms of city, time and length.

This will establish the aircraft availability for extra usage, given the current routings.

b. Identification of exchange points.

The exchange points are the places in time where two aircraft are at the same city at the same time and each could perform the other's next allocated flight. These constitute the basic means of aircraft rerouting.

c. Generation of "what-if" situations.

It is important to be able to experiment with the aircraft routings without necessarily making the changes permanent, yet also to have the option to do so.

Thus the aim is to develop a set of interactive-graphic tools that will allow for modifications to a given schedule and set of aircraft routings. These graphic tools will help to make the DSS approach similar to the existing manual methods.

The key aspect involved in developing aircraft routings is that the planner needs a starting solution of routings that satisfy schedule requirements from which he can make adjustments for maintenance requirements.

The present approach at CP Air starts with basic cycles that are weekly flight patterns that could be operated by the aircraft. (1) Operational cycles are developed by rotating the aircraft onto the basic cycles in order to satisfy some maintenance requirements. Further adjustments to the operational cycles have to be made in order to satisfy all schedule and maintenance requirements. See Appendix A for a more detailed description.

Another approach used by other airlines is the computer generation of aircraft routings to meet schedule requirements and maintenance requirements.

The question then arises whether or not it is necessary to reproduce the present approach exactly, or if there are better ways of routing aircraft. Often the operational

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(1) These weekly cycle patterns were developed in schedule planning for many potential schedules, and were used to illustrate that the given schedule could be performed with CP Air's fleet.

cycles after adjustments do not end up resembling the basic cycles.

For now, the approach taken to aircraft routing will be to initialize the routings to meet basic schedule requirements, then modify them with the above tools to obtain the planned aircraft routings that satisfy all schedule and maintenance requirements. If desired, these routings can be first modified to resemble the weekly cycle patterns. The tools can then be used to handle all subsequent changes.

CHAPTER 3

SYSTEM CAPABILITIES

3.1 Overview

The following sections describe the basic functions provided by the system.

3.1.1 Aircraft Routings

A First-In-First-Out (FIFO) algorithm is used to route the aircraft considering schedule requirements of aircraft type and seating. See Appendix B for a more detailed description of this program. These routings are copied to the interactive system for further manipulation. Within this system, two sets of routings are maintained, a working version and a permanent version. Modifications are made only on the working version, but at any point this version can be made permanent. Alternatively, at any point the working version can be reset from the permanent.

3.1.2 Typical Display Elements

The following is a description of the basic elements that would be found on a display.

1. Season of the current schedule.

   An example of this would be 'S : W85' for indicating that the information is from the Winter 1985 schedule.

2. Timeline corresponding to the display.

   All times used are GMT times (Greenwich Mean Time), where each date is shown as YYMMDD/day of week, separated by hour counts to indicate the relative flow of time.

3. Aircraft tail numbers.

   Presently tail numbers which uniquely identify the aircraft, are shown along the vertical axis of the display. Consideration will be given to whether aircraft type and/or configuration need to be shown.

4. Display of routings corresponding to tail numbers.

   A routing is typically displayed as a sequence of flight numbers with downtime periods in each city highlighted with color bars. These downtime periods have been colored for the major cities, places where aircraft are commonly exchanged. For instance, Vancouver is colored blue, and Toronto green. The arrival and departure times are marked below the bars.

5. Definition of Program Function keys.

   There are several sets of program functions available. A definition of the current set is displayed at all times.

6. Function indicator.

   The name of the function currently in use is

labelled, in order to clarify whether the system is waiting for the user to complete a function, or awaiting the next. In the latter case the indicator will display 'CMD : '.

7. Command/Message line.

   This field confirms with the user the task he is performing with the program function keys and the cursor. In general, the system will await for a Perform or Abort signal before proceeding. This field is also used to build and view flight messages, as well as reporting to the user any error messages.

3.1.3 Window Concept

The main problem with creating ways of displaying information on a screen, is that the user is accustomed to seeing larger quantities of information at a glance. The manual charts show one week of routings for either the wide or narrow-body aircraft. To compensate for this the display behaves as if a window were placed on top of the aircraft utilization charts. The following functions are provided to control the movement of the window:

1. LEFT/RIGHT moves the window backwards and forwards in time
2. HLEFT/HRIGHT moves the window half a screen back or forward in time
3. UP/DOWN moves the window up and down through the aircraft.

3.1.4 Time Intervals

In order to allow for seeing an overall picture of the routings as well as the detail, four different displays are available, each with varying amounts of information.

1. The seven-day display shows the flight numbers of the aircraft routings for a one-week period. This is similar to the routings maintained on the walls in Operations Control and Maintenance Planning.
2. The three-day display shows the flight numbers and downtime periods of the aircraft routings. Downtime periods that are approximately one hour, only warrant one column on the display and are asterisked to indicate that the airport code has been omitted.

   The main use for this display would be to scan for large downtime periods or exchange points.
3. The one-day display shows the flight numbers, downtime periods and GMT times for a one-day time interval. Information that had to be omitted due to space limitations is asterisked. Each column represents twenty minutes.
4. The eight-hour display is the most detailed and indicates the same information as the one-day. In general, no information has to be omitted from this display. Each column represents approximately seven minutes.

Functions are provided for moving between the different displays. They are:

1. ZOOM to a smaller time interval.
2. WIDE to a larger time interval.

3.1.5 Adjusting View

One problem with the present manual method is cross-referencing aircraft, especially when they are in separate books.

The following functions were provided to help in this area:

1. SELECT specific aircraft to be grouped together.
2. SORT the aircraft by downtime in a particular airport. This will move all aircraft that are in the specified airport code for the time interval currently being viewed to the top of the display in order of decreasing downtime size.
3. FIX an aircraft to the top of the display. This will allow a specified aircraft to be displayed at all times, and thus compared against all other aircraft with the window functions.
4. SPLIT will simultaneously display the temporary and permanent routings, so that changes can be compared against the original routings. This referencing back allows the user to have a better understanding for the consequences of his changes, as well as indicating what

further changes are necessary in order to bring the aircraft back to the original routing at the earliest possible place.

3.1.6 Updating of Data Base

In order to understand the update functions, the following terms have been defined for this project.

Flight Sector is the service provided between a city pair with a defined origin and destination city, characterized by departure and arrival times.

Flight is a combination of one or more flight sectors, characterized by a common flight number and aircraft requirement.

Flight Occurrence is the scheduled service of a flight on a particular date in time.

Aircraft Routing is the assignment of flight occurrences to the aircraft.

The aircraft routings can be modified with the following functions:

1. SWAP the aircraft routings at the exchange point specified by two flight occurrences.
2. REASSIGN a flight occurrence to another aircraft.

Capabilities for updating flight information are:

1. ADDNEW adds a new flight to the data base and assigns

an occurrence of it to the specified aircraft.

2. ADDOLD assigns a new occurrence of a flight already in the data base to the specified aircraft.
3. CHANGE modifies the flight information for a flight occurrence, by creating a new flight and replacing the old flight occurrence with a new flight occurrence.
4. DELETE removes a flight occurrence from an aircraft.

In both the CHANGE and DELETE options, if there are no occurrences of a flight remaining, then the flight is removed from the data base.

Finally a facility has been provided to add, change, delete and view messages to a particular flight occurrence. These are indicated by a red flag on the flight number.

3.2 Sample Runs

Examples of the system capabilities can be seen in the following pictures.

The system is menu-driven with a main menu and submenus, as seen in Figures 3.1 and 3.2. Options 2 and 3 on the main menu for creating back-up versions of experimental routings, and for producing hardcopy output of selected information have not been implemented yet.

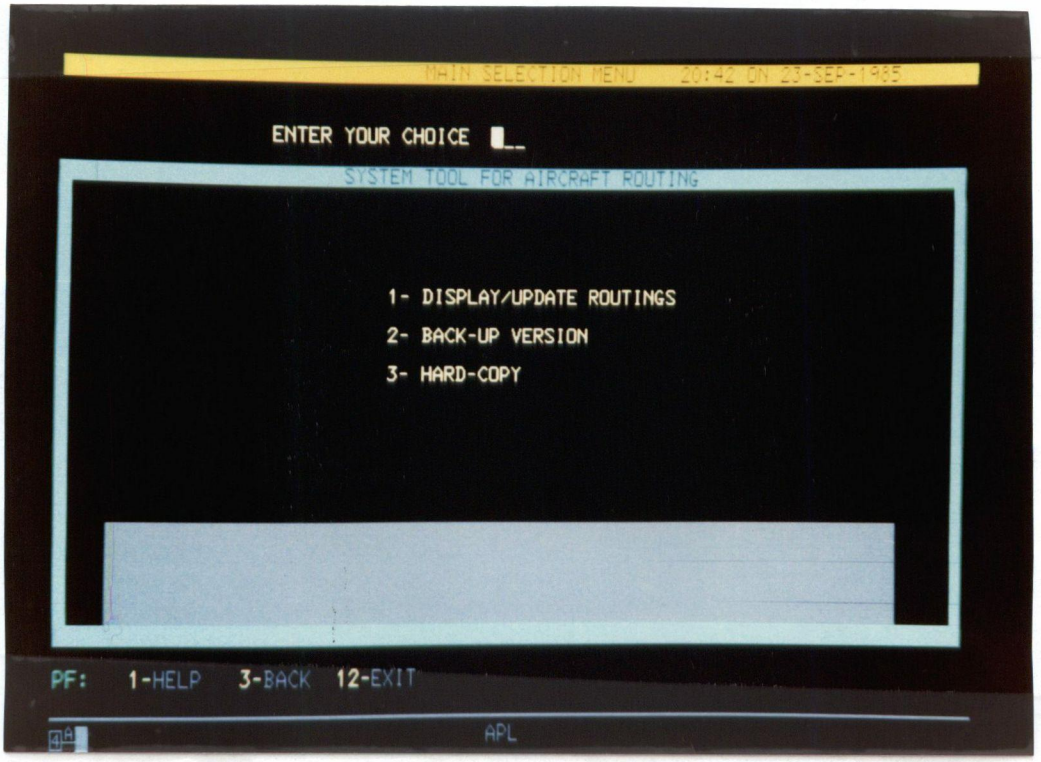

Figure 3.1
Main Selection Menu

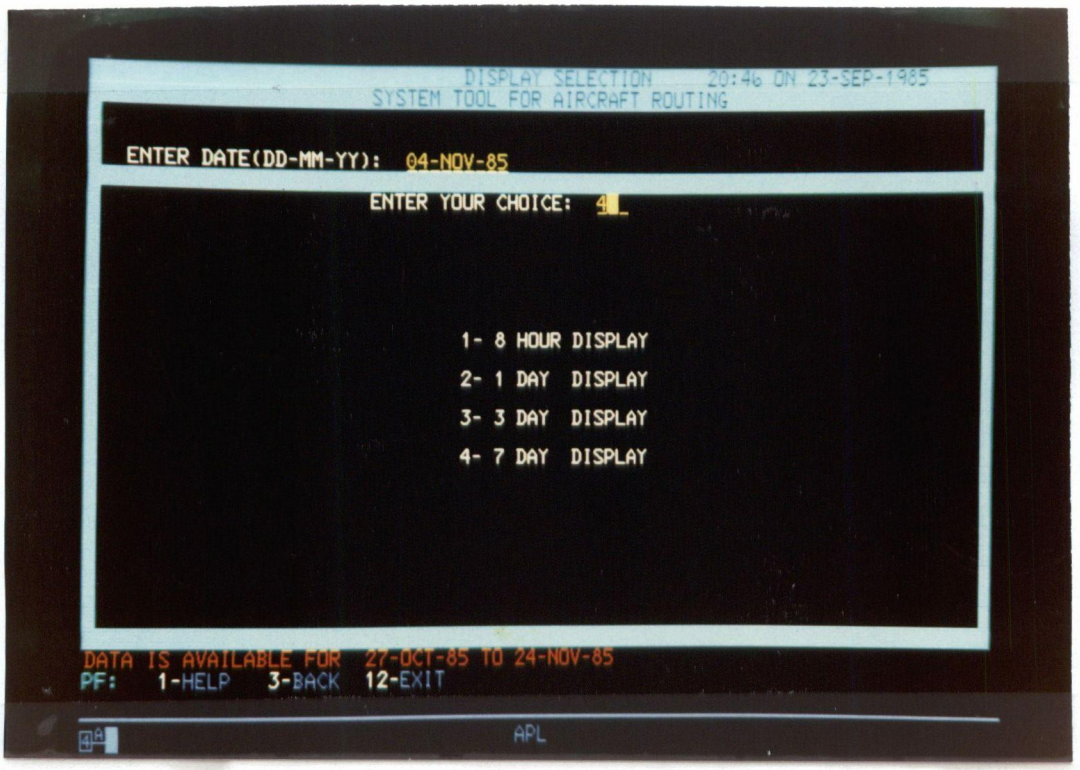

Figure 3.2
Display Selection Menu

Figures 3.3 to 3.8 display the various time intervals for viewing the routings, as well as several windowing options.

Figures 3.3 and 3.4 illustrate the seven-day display with the use of the DOWN option to view from the wide-body aircraft to the narrow.

The cursor was moved from November 4 to November 6 before ZOOMing to the three-day display, as seen in Figure 3.5, and ZOOMing again to the one-day display is seen in Figure 3.6.

The HALF-SCREEN LEFT option is illustrated in Figure 3.7. The Cursor was then repositioned to the time interval desired before ZOOMing to the eight-hour display.

The ZOOM facility analyses the cursor position, and zooms to the corresponding time interval, positioning the top of the window on the aircraft identified.

S: W85

	851104/1	851105/2	851106/3	851107/4	851108/5	851109/6	851110/7
741	3	4-3	4		315		316
742	388-387	4		3	4		
743		3-38	381	301-302		301-302	
744	61-80		311	322-323	312	3	4
901	5		6	384	285-284	201-200	285
902	202-203	478-479	284	285-214	215	478-479	284
903	4	284	285	284	387	5	

PFKEY: 1=OPT 3=END 5=ZOOM 7=UP 9=HLEFT 11=RIGHT
2=NEWPF 4=VIEWMSG 6=WIDE 8=DOWN 10=LEFT 12=HRIGHT

CMD :

Figure 3.3
Seven-day Display

S: W85

	851104/1	851105/2	851106/3	851107/4	851108/5	851109/6	851110/7
753	28-21-965-54-962	18-7-63-53-964	28-21-965-54-962	18-7-63-53-964	28-21-965-54-962	18-7-63-53-964	65-964
706	22-23-944-989	948-985	59-30-72-975	35-50-84-26	29-20-91-996	26	23-985
707	77-31-651-652-254	257-40-92-16	95-90-27	948-985	59-30-72-975	35-50	51-42-43-56-57
708	266-267-50-84-26	29-20-91-996	22-23-944-989	77-31-42-43-44-45	621-622-640.1	628-250-253	66-90-27
709	46-41-52-55-44-45	621-622-260-263-254	257-40-92-16	95-90-27	948-985	59-609-604-605-606	258-251-32
710	257-40-92-16	95-90-27	948-985	59-30-72-975	35-50-84-26	29-971	33-607-606
711	626-36-970-24-25-967	258-251-605-606	58-643-640-661	662-82-17-89	51-260-263-607-606	58-51-42-43-44-45	603

PFKEY: 1=OPT 3=END 5=ZOOM 7=UP 9=HLEFT 11=RIGHT
2=NEWPF 4=VIEWMSG 6=WIDE 8=DOWN 10=LEFT 12=HRIGHT

CMD :

Figure 3.4
Seven-day Display with DOWN Option

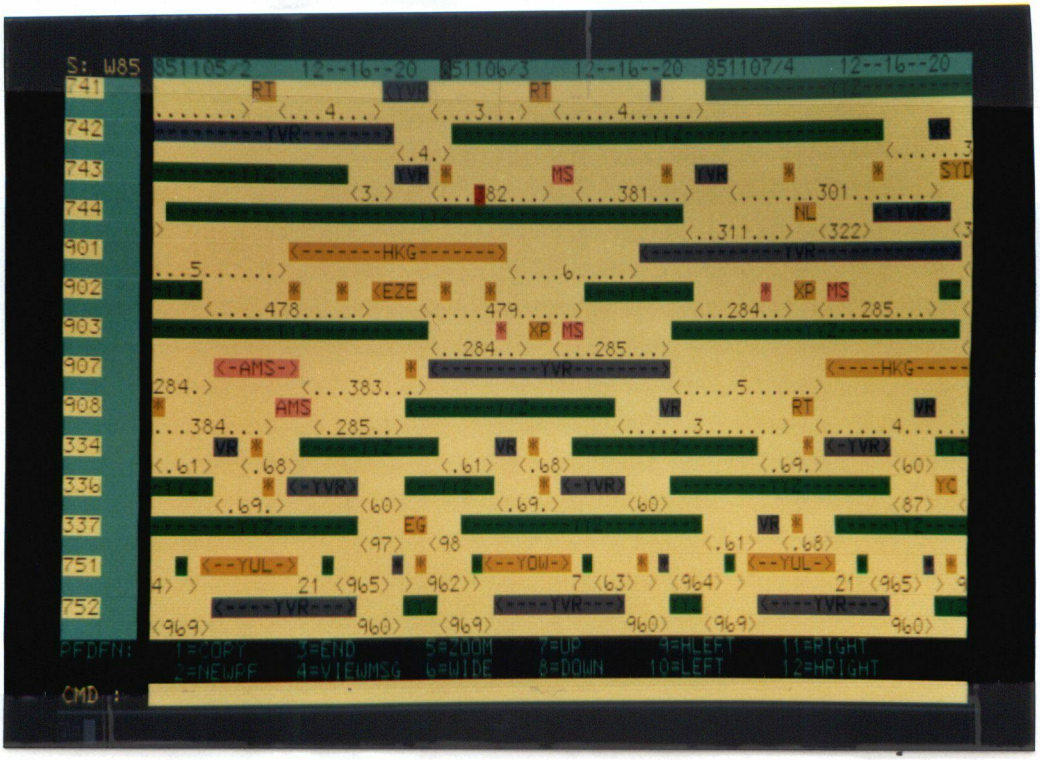

Figure 3.5
ZOOM from Seven-day to Three-day Display

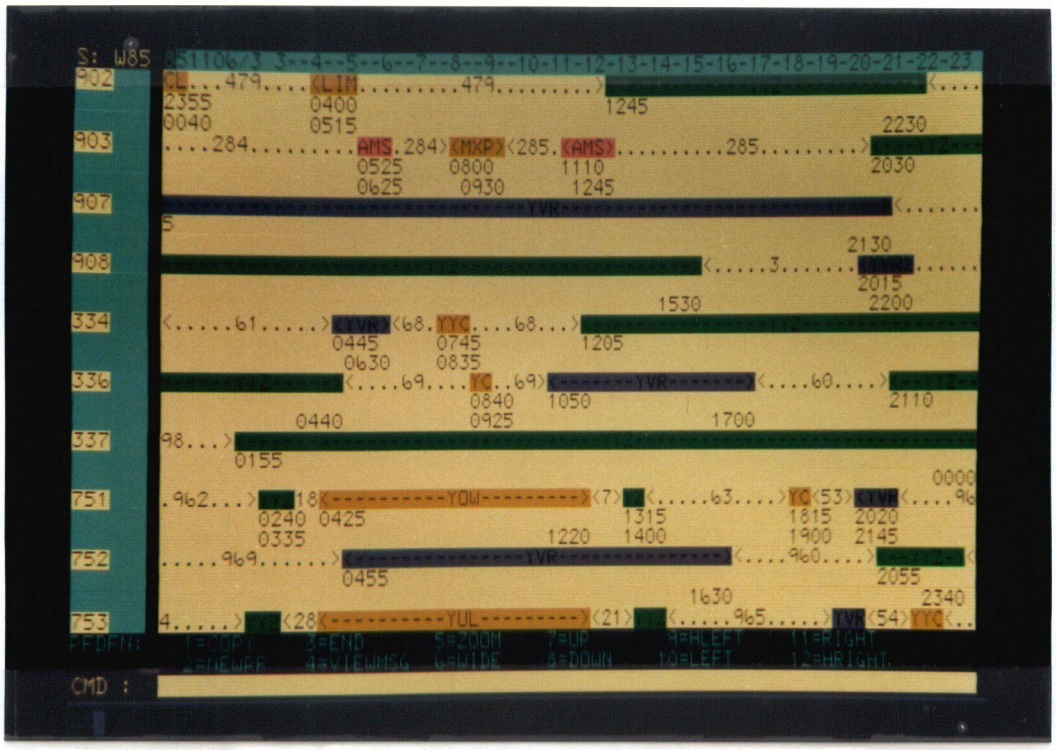

Figure 3.6
ZOOM from Three-day to One-day Display

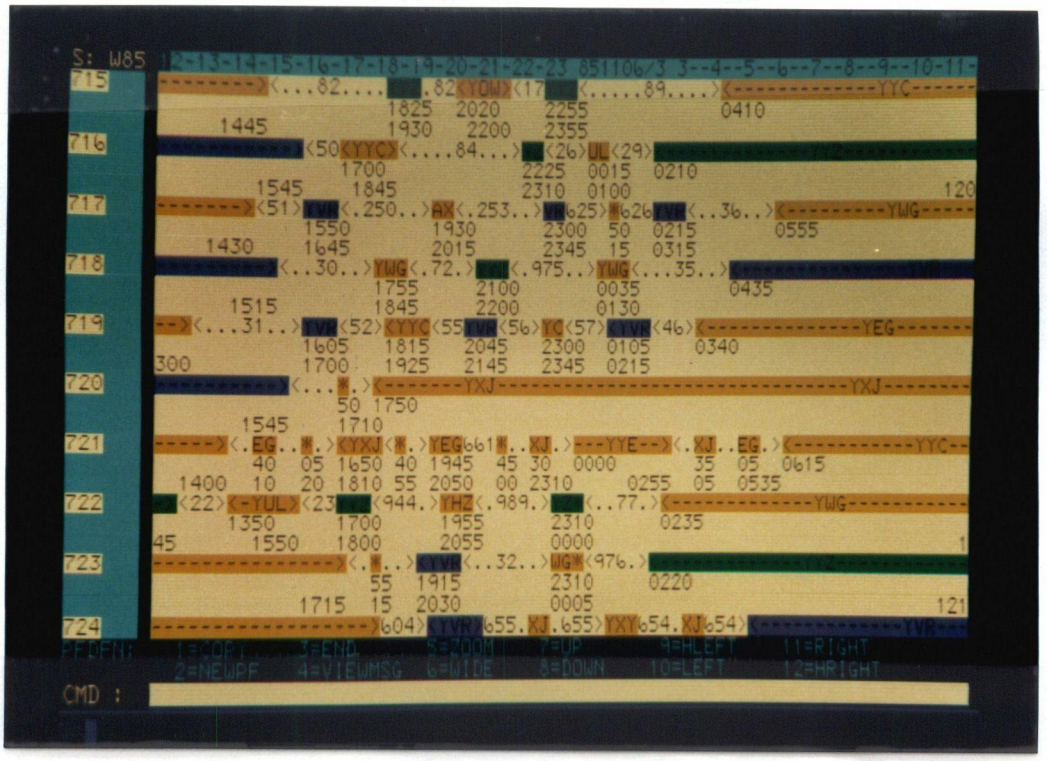

Figure 3.7
HALF-SCREEN LEFT Option

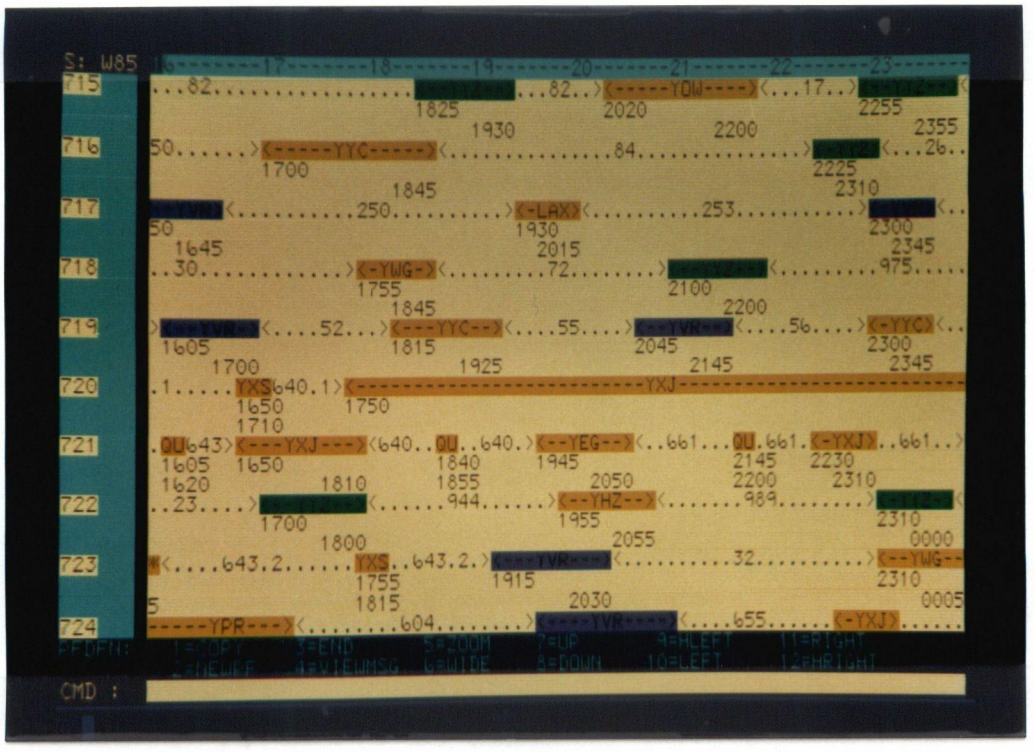

Figure 3.8
ZOOM to Eight-hour Display

Figures 3.9 to 3.14 illustrate the facilities for adjusting the view of the current information. This requires changing to a new set of program function keys, as seen in Figure 3.9.

A set of aircraft were selected in Figure 3.10, which resulted in each of these being moved to the top of the display.

The FIX option was used to place aircraft 751 in a fixed field at the top of the display in Figures 3.11 and 3.12.

The SORT option is illustrated in Figure 3.13, where it has sorted the aircraft in Vancouver (YVR) for November 6. This option sorts over whatever time interval the user is currently viewing.

The SPLIT SCREEN option (Figure 3.14) displayed the permanent routings above the temporary routings, separated by the date line.

A new aircraft ordering established by the SORT or SELECT option is maintained until either it is cancelled by using one of these options again, or the original ordering is RESTOREd. Similarly for the FIX and SPLIT SCREEN options. This allows for using the facilities on the other program function sets with the new view established.

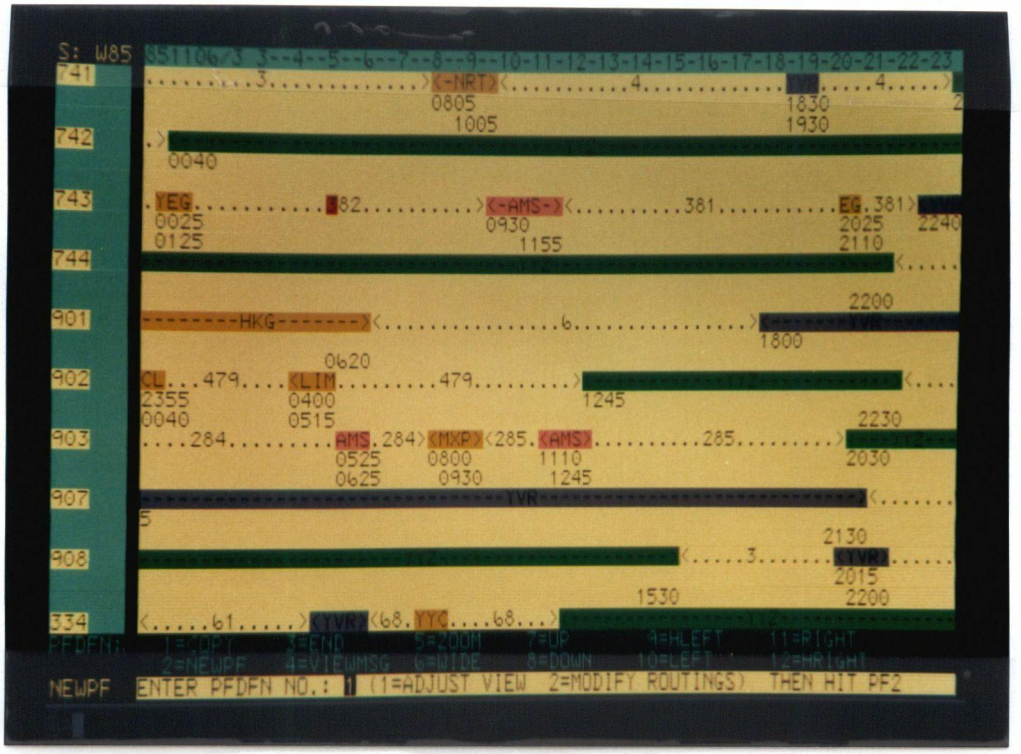

Figure 3.9
NEW PROGRAM FUNCTIONS Option

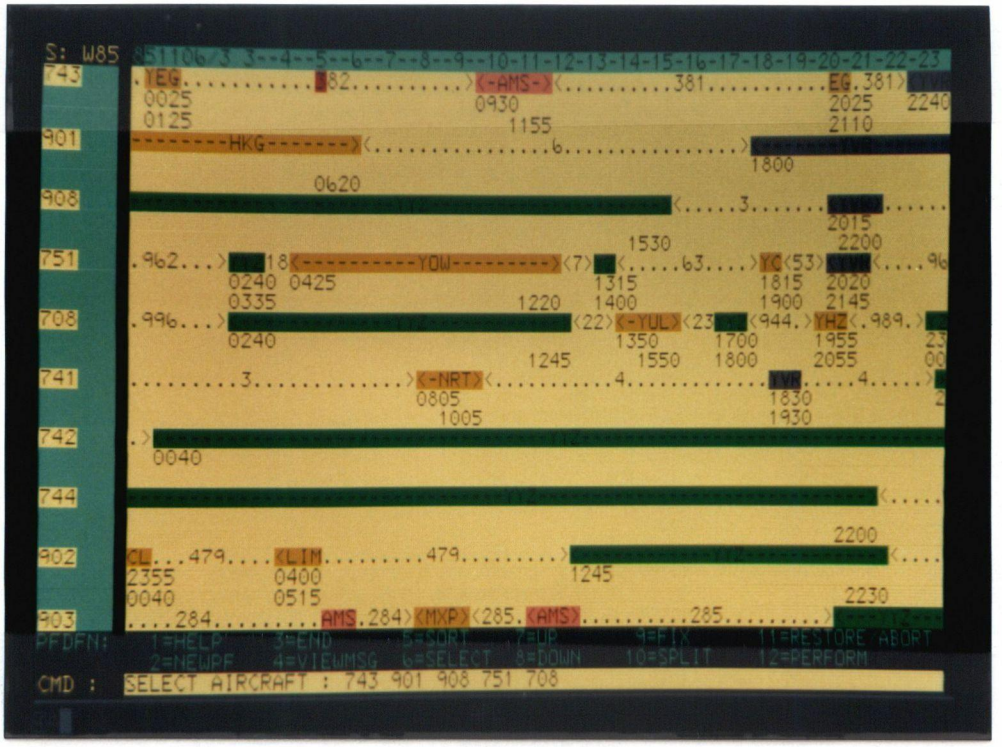

Figure 3.10
SELECT Aircraft Option

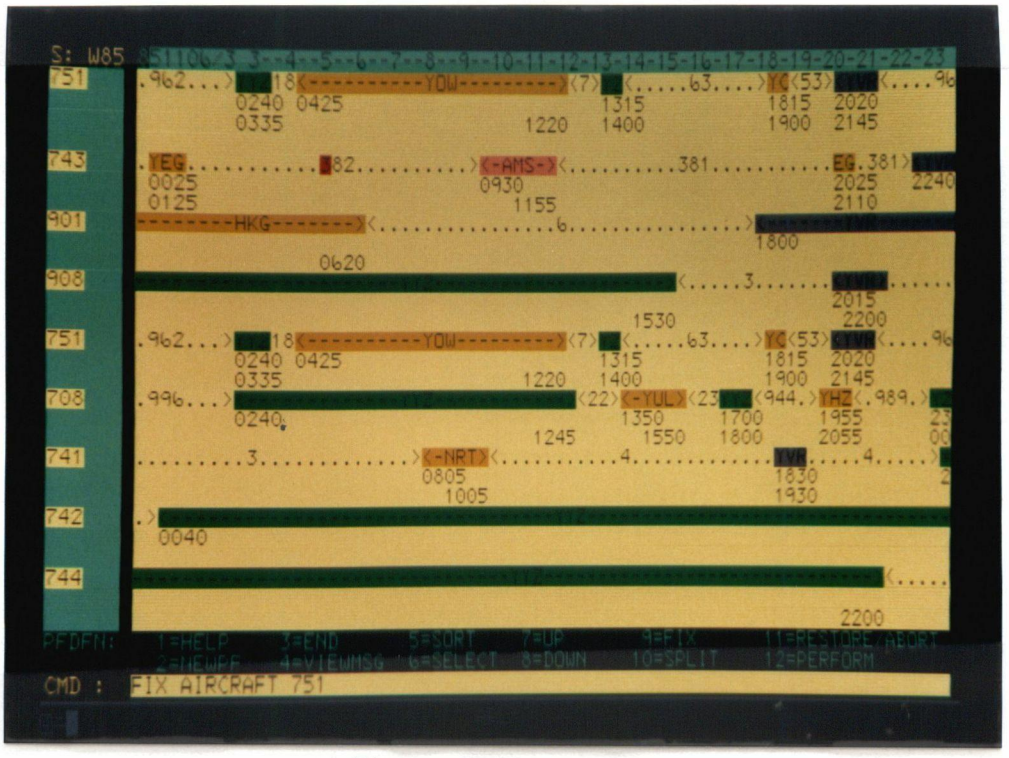

Figure 3.11
. FIX Aircraft Option

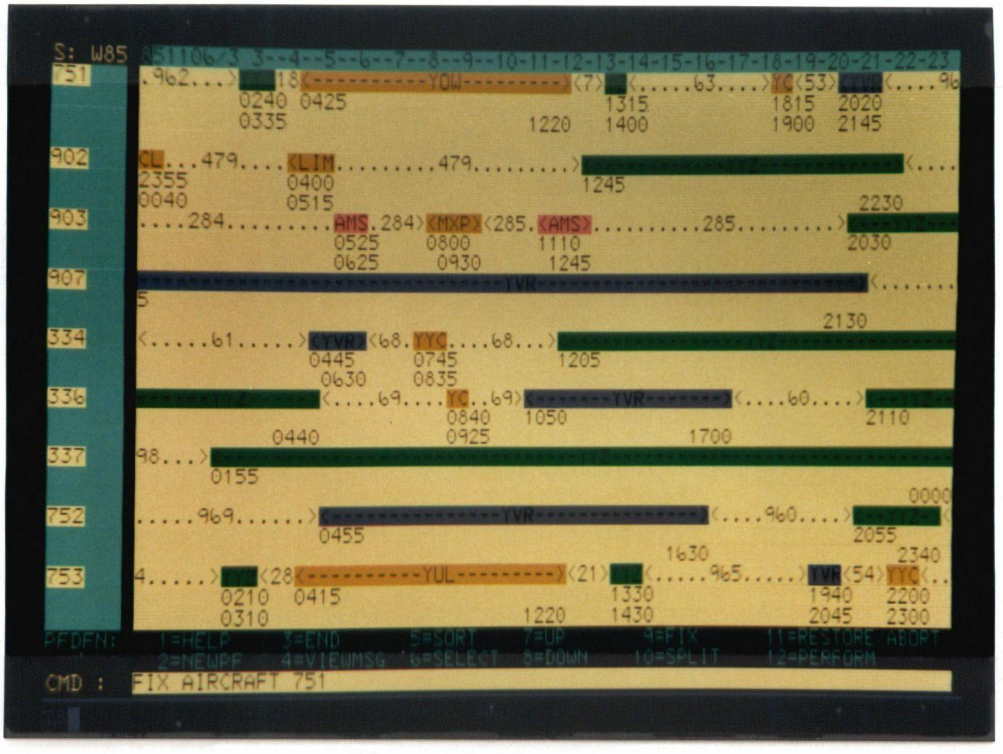

Figure 3.12
FIX Aircraft with DOWN Option

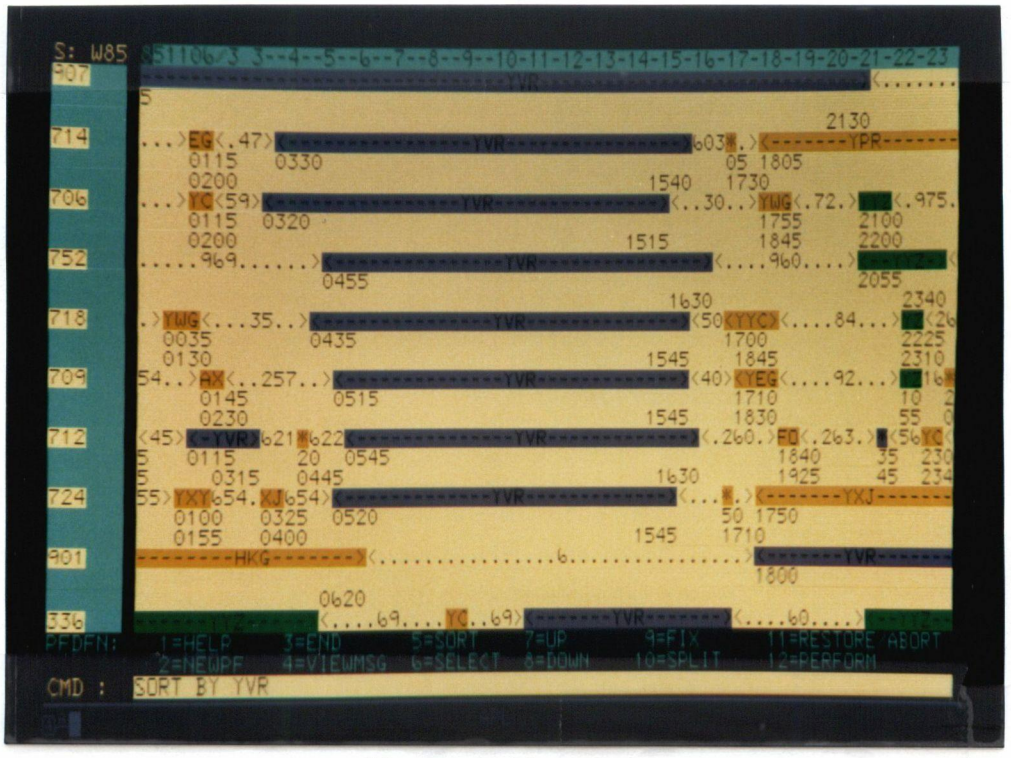

Figure 3.13
SORT by Downtime Option

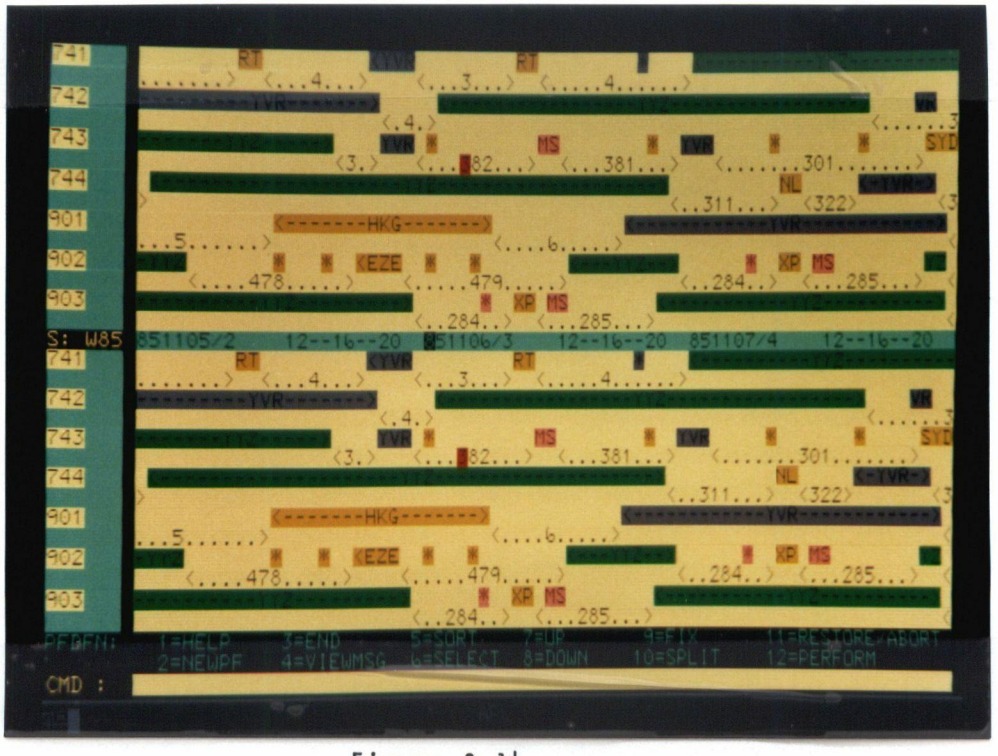

Figure 3.14
SPLIT SCREEN Option

Figures 3.15 to 3.22 illustrate the facilities for rerouting the aircraft. These are located on the Modify Routings choice when changing to a new set of program function keys.

The first sequence illustrates the SWAP facility, where the user must specify an exchange point by identifying two flights occurrences with the cursor. See Figures 3.15 and 3.16. A flight occurrence is always identified by placing the cursor anywhere on the area from the downtime preceding it, to the end of the flight occurrence.

The system then waits for the user to give the action signal (PF11 = ABORT function, PF12 = PERFORM function) before proceeding.

At this point the system validates the input, checks that cities match, and checks the times. If the turnaround times (time intervals between consecutive flights occurrences) are less than a specified minimum, then the system flags this and waits for permission to proceed. Any errors are flagged and the function is aborted.

Figure 3.17 shows the routings swapped at the specified exchange point.

In Figure 3.18, an exchange was performed two days later to bring the aircraft back to their original routings. This is commonly referred to as bringing the aircraft "back to cycle".

The REASSIGN option proceeds in a similar fashion to the SWAP option. Figures 3.19 to 3.22 illustrate the

reassignment of flights 69 and 60 on November 6, from aircraft 336 to aircraft 337. The main difference between the SWAP option and the REASSIGN option is the added flexibility of being able to reallocate single flights occurrences, especially if an aircraft must be flown empty in order to position it. The '?'s on the downtime interval indicate that the cities on the routings do not match.

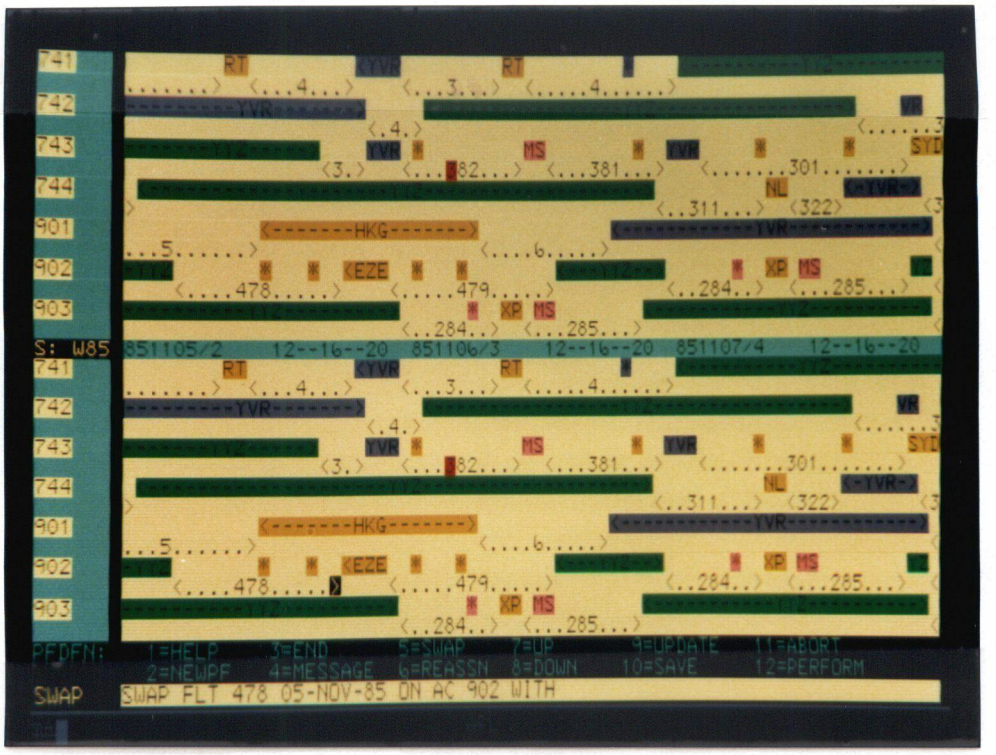

Figure 3.15
SWAP Option : Select first flight

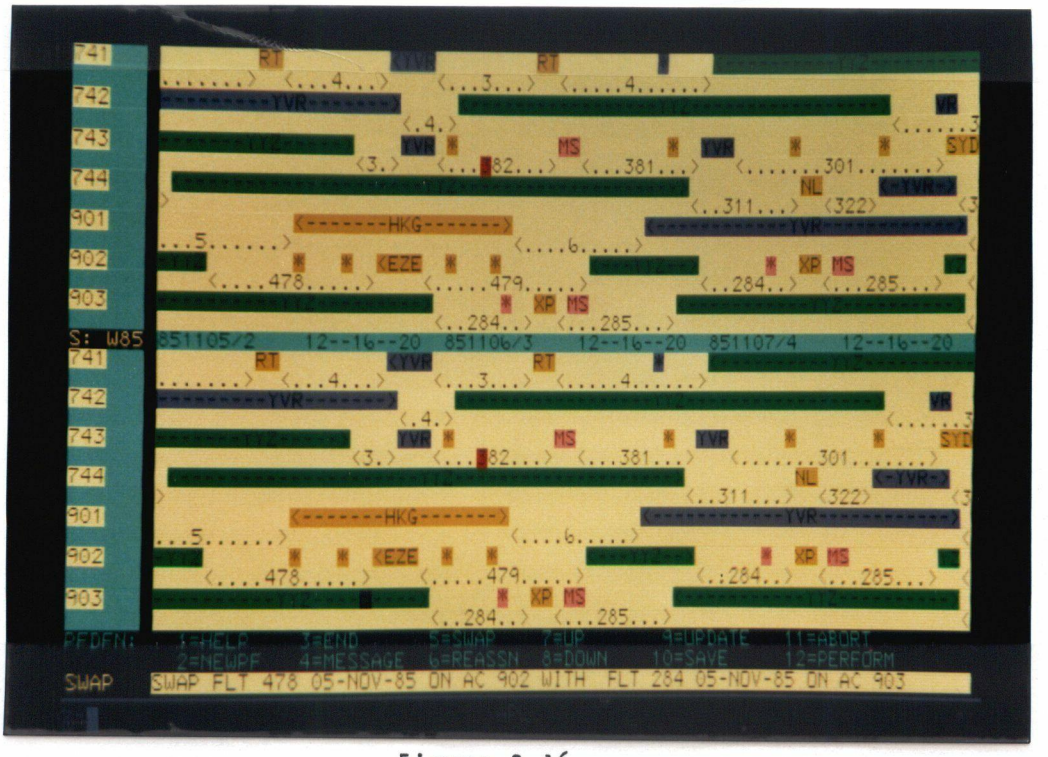

Figure 3.16
SWAP Option : Select second flight

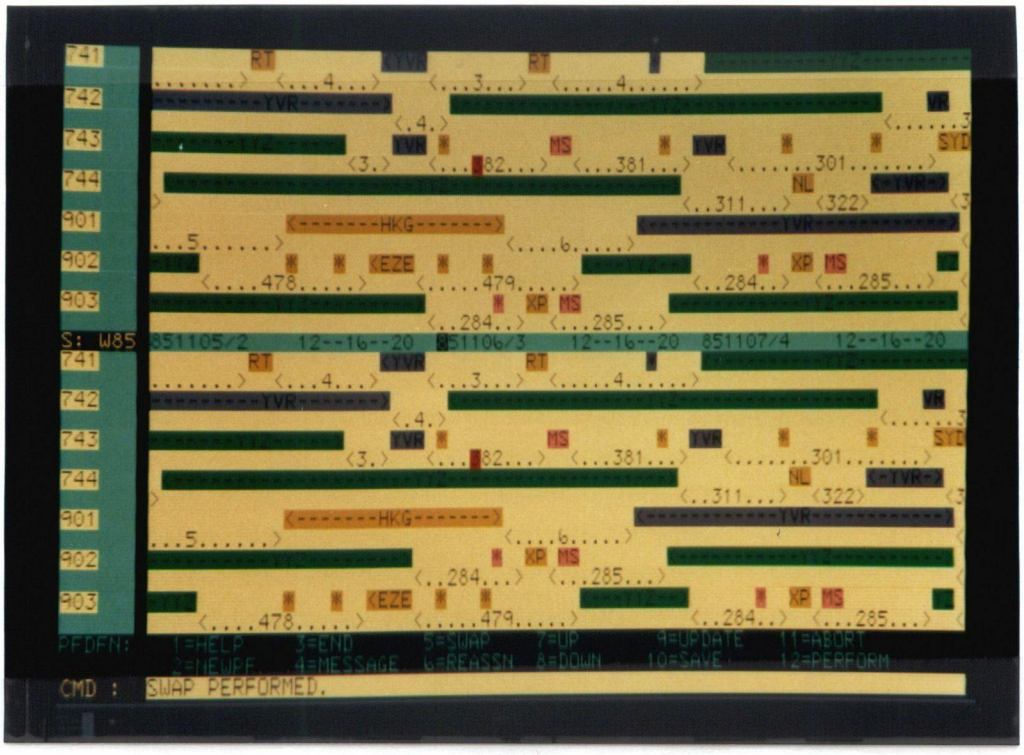

Figure 3.17
Aircraft Routings Swapped

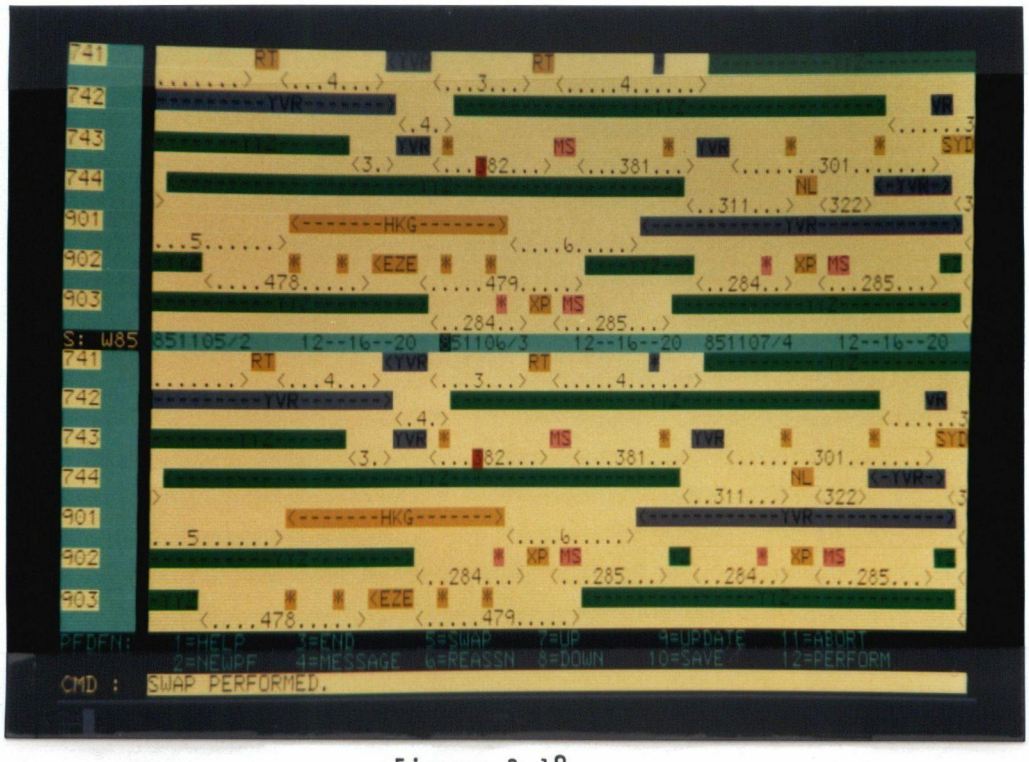

Figure 3.18
Aircraft Routings Brought Back to Cycle

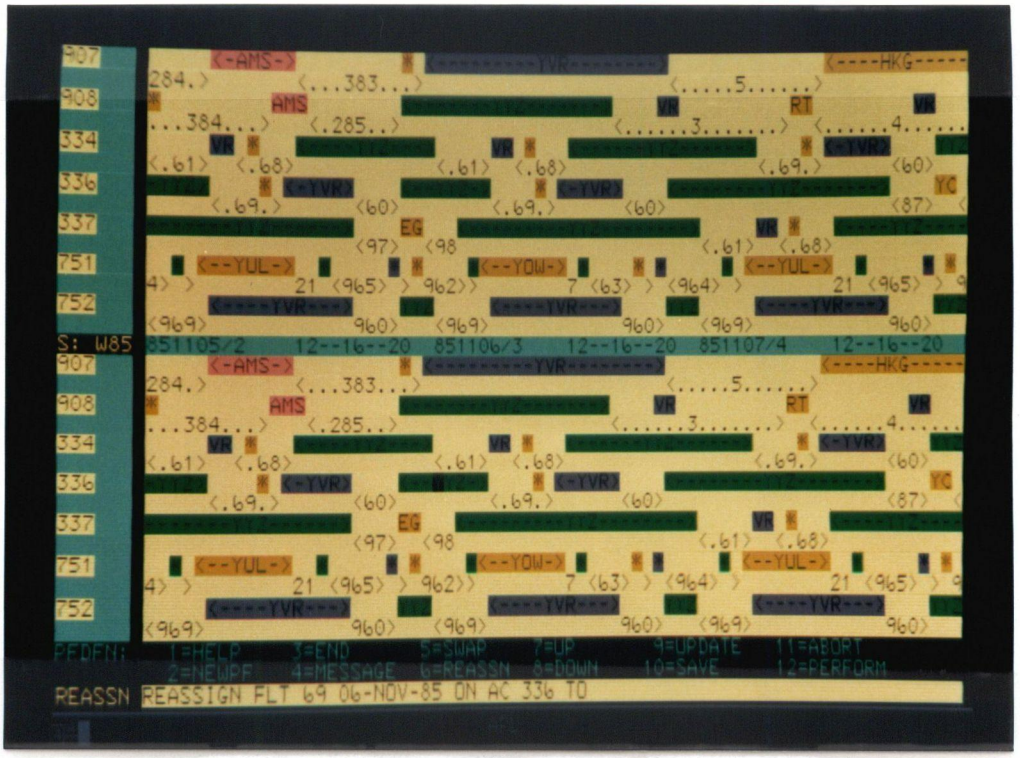

Figure 3.19
REASSIGN Option : Select Flight

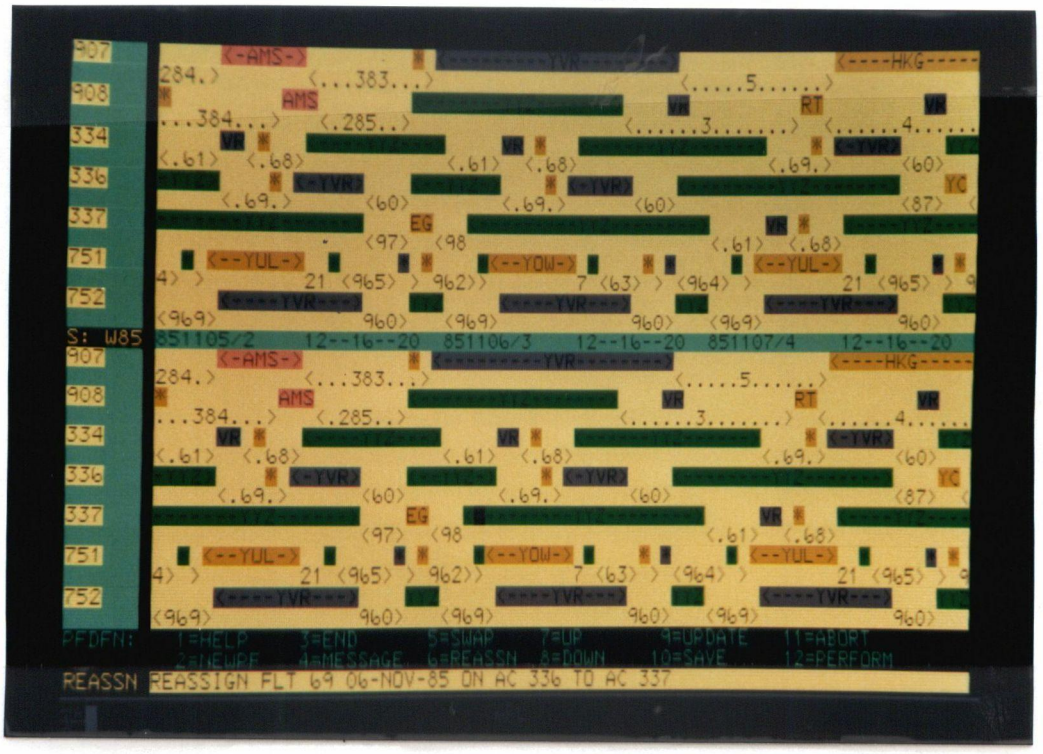

Figure 3.20
REASSIGN Option : Select Aircraft

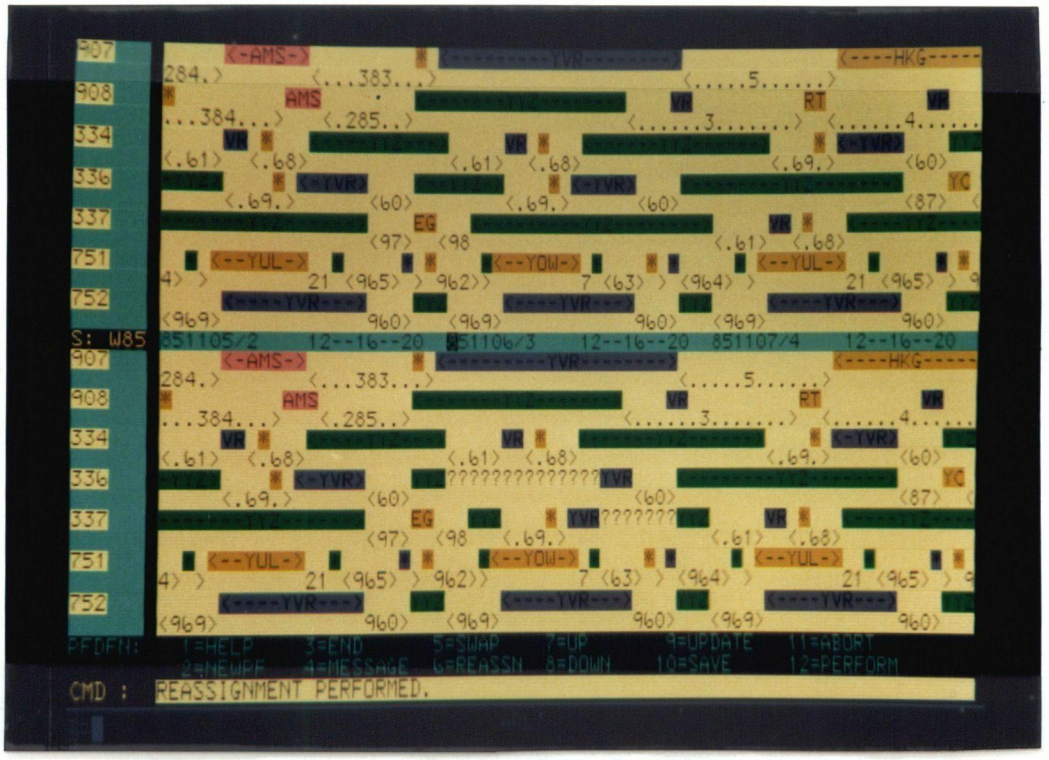

Figure 3.21
Flight Reassigned

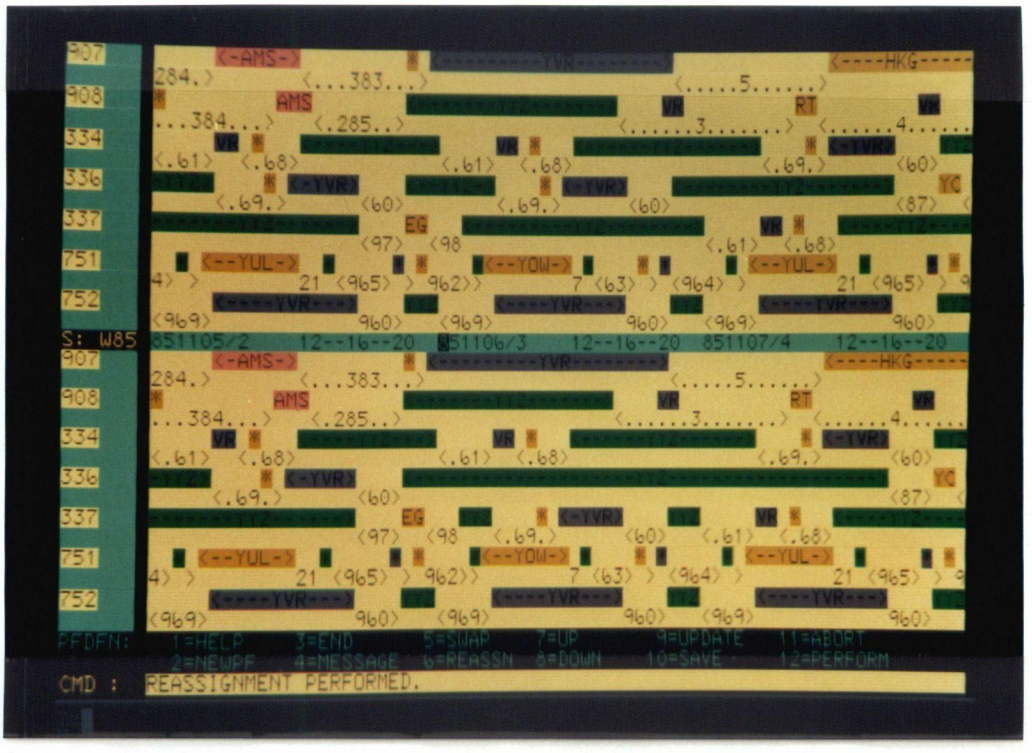

Figure 3.22
Second Reassignment to Match up Flights

Figures 3.23 to 3.30 illustrate some of the options for updating flight information. These are located on the UPDATE option of the Modify Routings program-function keys.

The VIEW FLIGHT facility displays flight information for the flight indicated by the cursor. This is particularly useful when information had to be omitted, or the user wishes to view the flights outside the edges of the window, as seen in Figures 3.23 and 3.24. (In Figure 3.23, there was not enough room to write the flight number, 260)

By VIEWing a flight and then using the ADD OLD Option, the user can add another occurrence of a flight already in the data base. (Not illustrated in figures.)

The ADD NEW option allows the user to add a new flight to the data base. The user first specifies where he wishes to place the flight, then fills in the flight information on the table provided. The system waits for the PERFORM signal before processing the validity checks. If there are any errors, then the system flags a message and the user is requested to modify the information or ABORT the function. Similar to the SWAP option, the system needs approval if the turnaround times are less than the minimum required. The information then is added and redisplayed.

Figures 3.25 and 3.26 illustrate the ADD NEW option, where a maintenance period has been added to the downtime.

The CHANGE option (Figures 3.27 and 3.28) was used to change the times for this maintenance period. Similar checks to the ADD options were performed.

The DELETE option (Figures 3.29 and 3.30) was then used to remove this maintenance period.

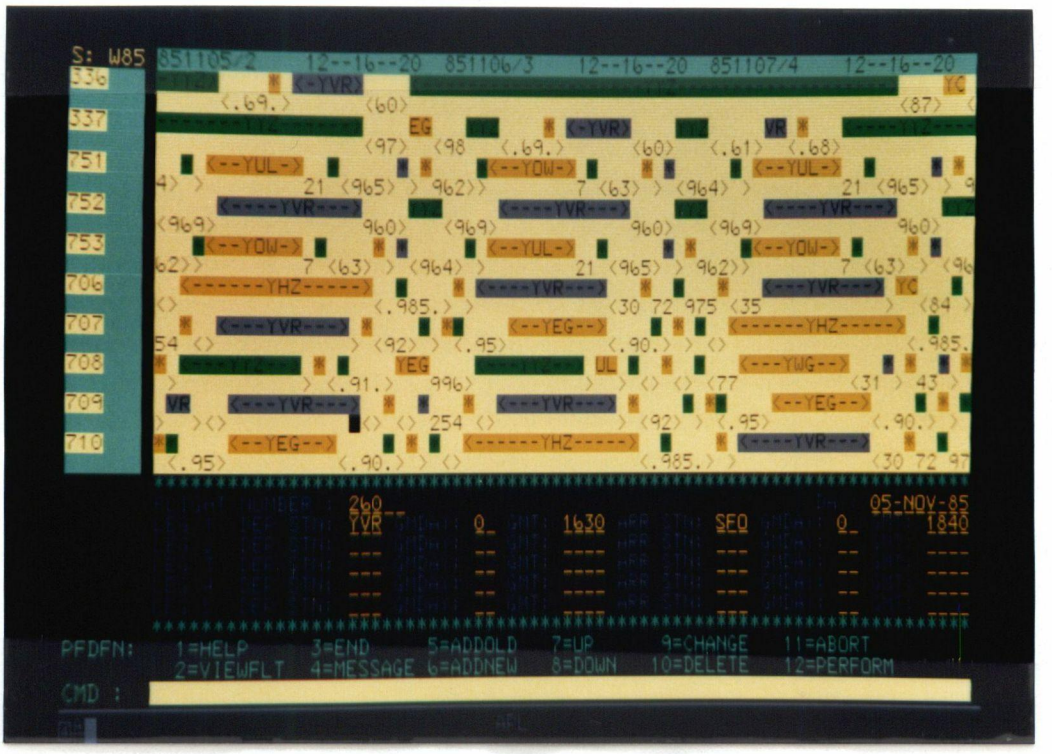

Figure 3.23
VIEW FLIGHT with Omitted Information

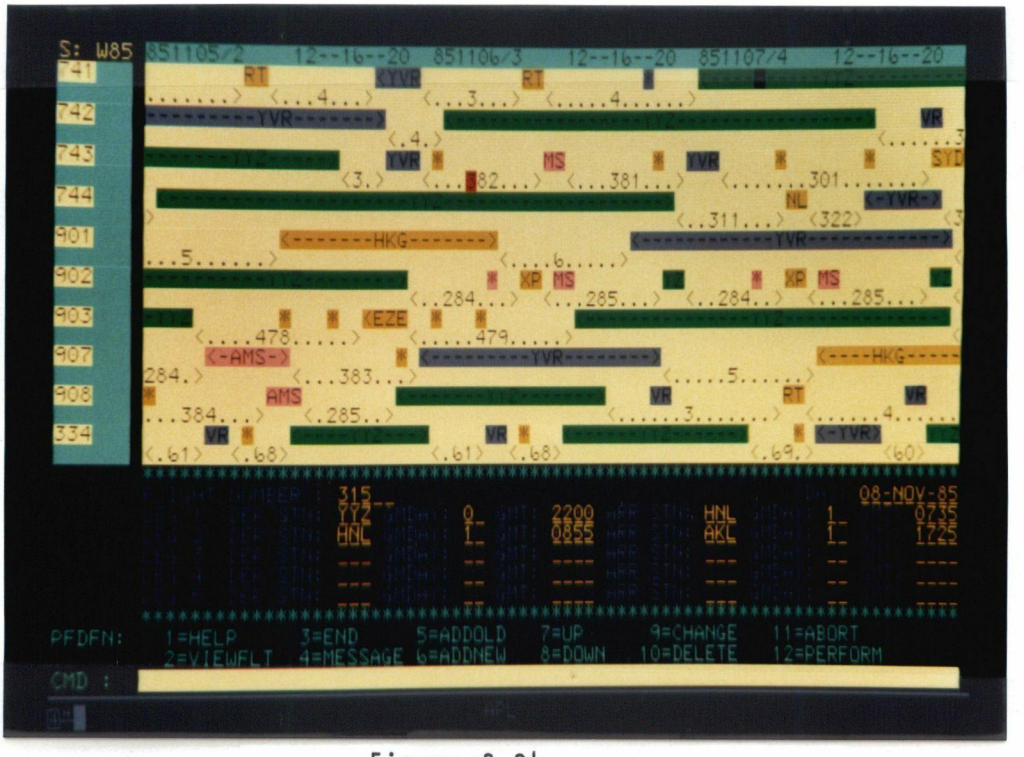

Figure 3.24
VIEW FLIGHT Outside Window

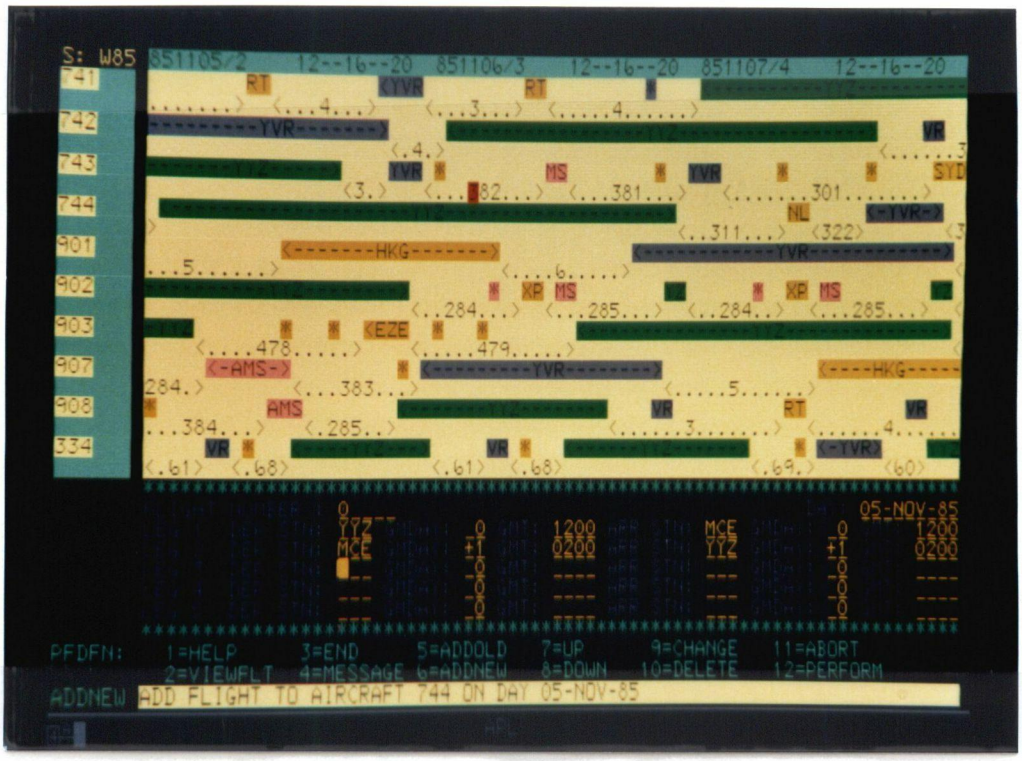

Figure 3.25
ADD NEW Option : Select Location and Add Information

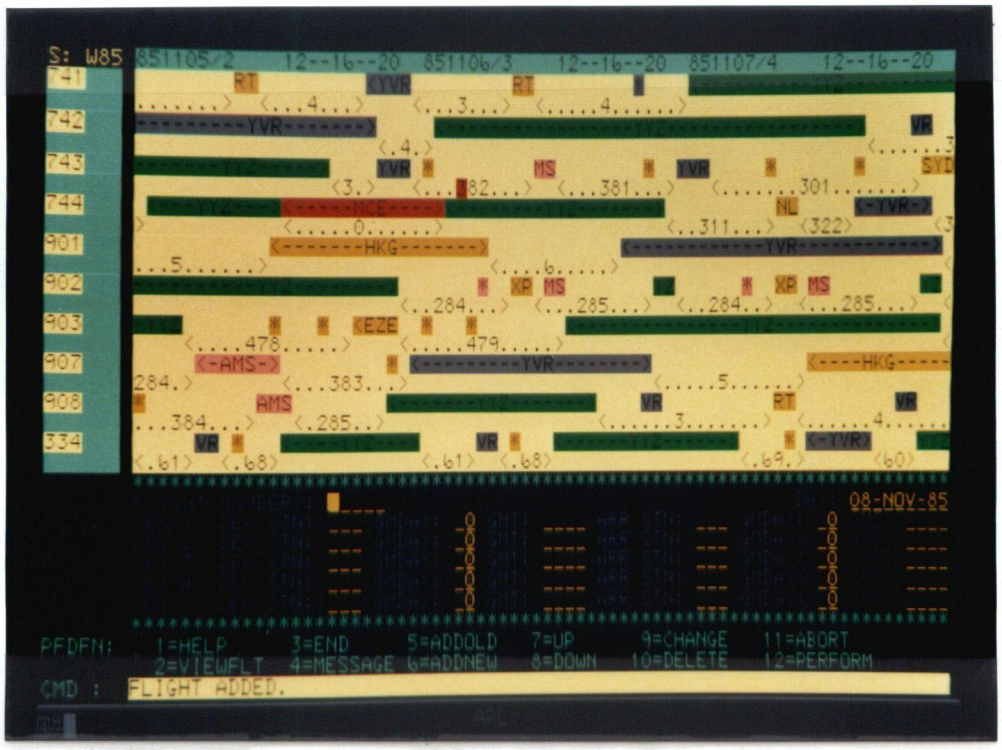

Figure 3.26
New Information Added and Displayed

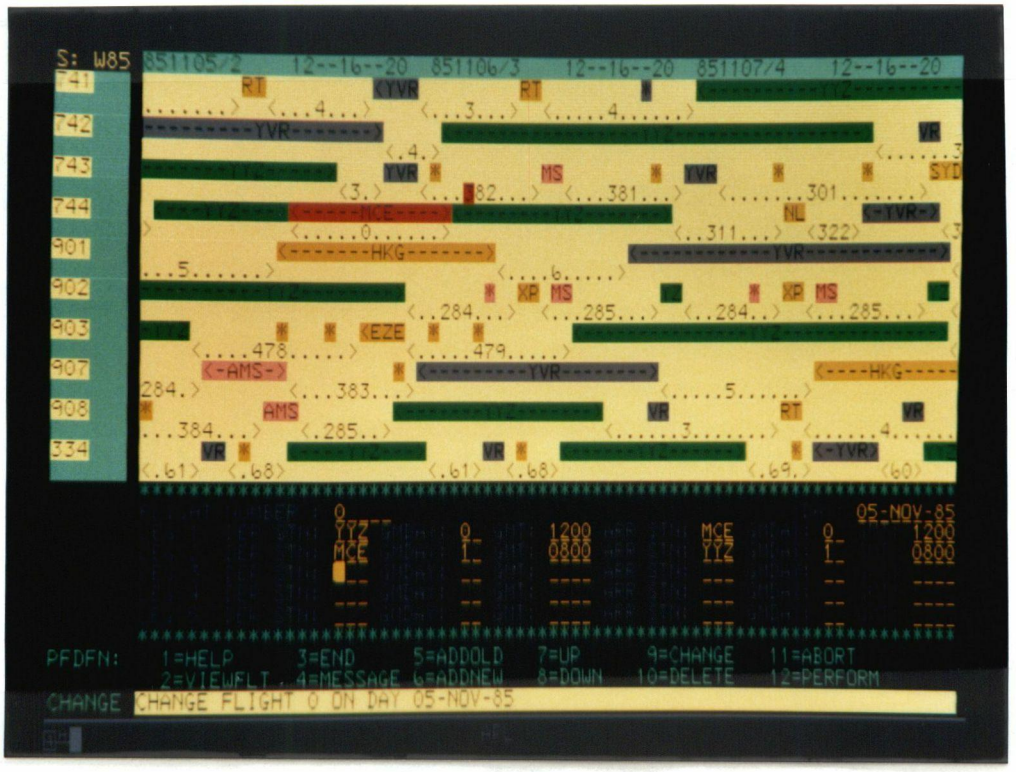

Figure 3.27
CHANGE Option : Select Flight and Change Information

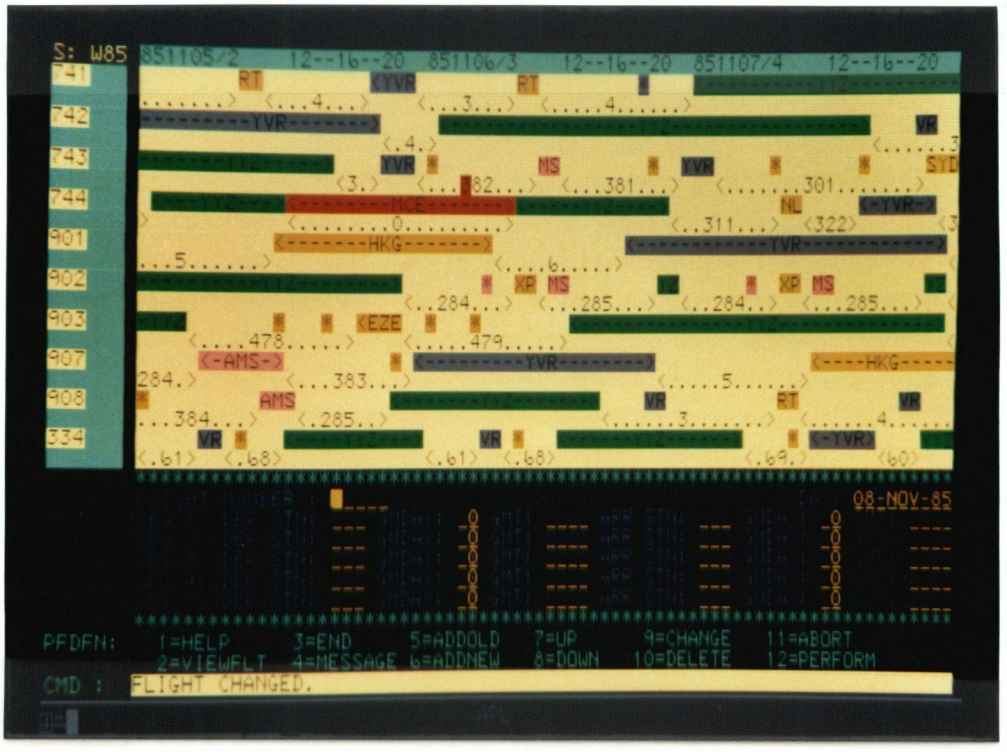

Figure 3.28
Information Changed and Displayed

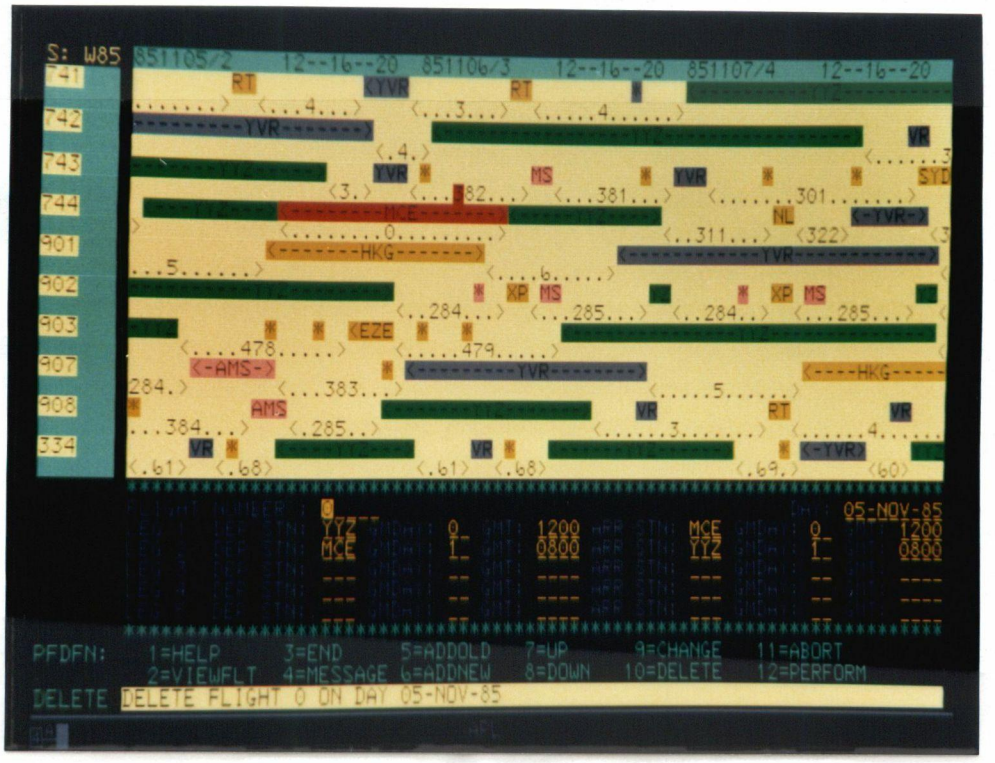

Figure 3.29
DELETE Option : Select Flight and View Information

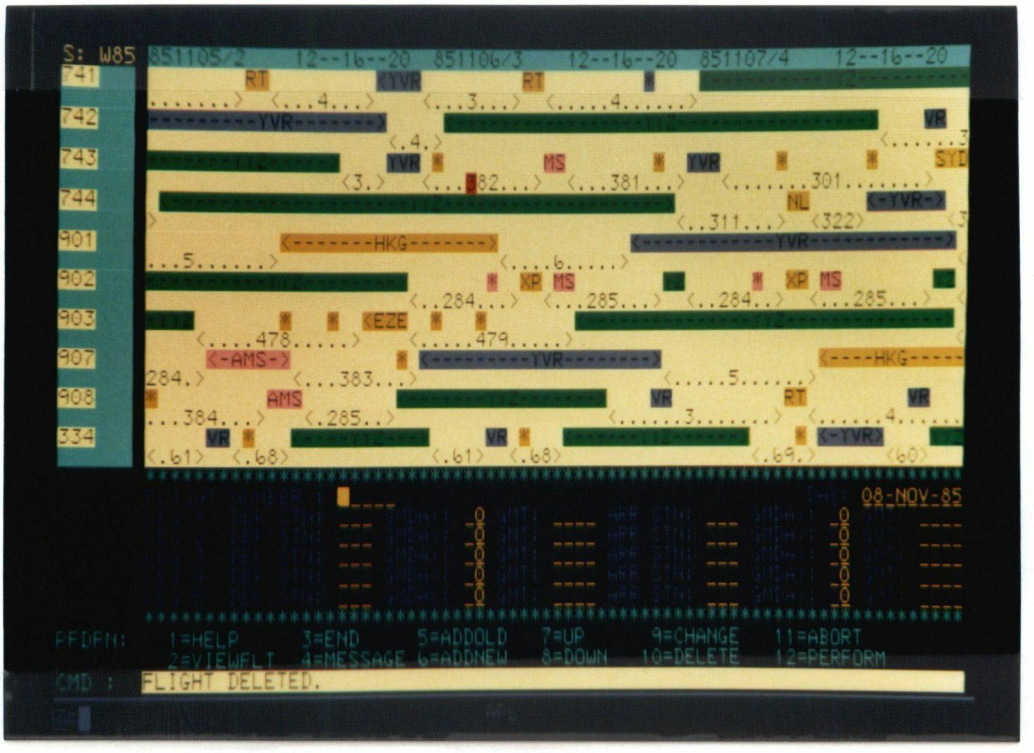

Figure 3.30
Information Deleted and Displayed

CHAPTER 4

BASIC ELEMENTS OF THE INTERACTIVE SYSTEM

4.1 Data Structures

Important considerations in setting up the data structures were:

1. All structures should be dynamic and allow for changes.
2. Must be able to reference, reallocate and modify each flight occurrence.
3. Aircraft routings need to be stored for the period, referenced by date and allow for changes, i.e., aircraft exchanges should be easy to perform.
4. All the sectors of a flight are normally assigned to the same aircraft, so a flight occurence is chosen as the basic entity for the routings.

The data are stored in the following three basic groups:

1. Schedule Data

   Within this group, there are three categories.

   a. Schedule Characteristics

      - Season of schedule

   b. Flight Characteristics

      - flight numbers
      - number of flight sectors

- starting location of sector information

c. Sector Characteristics

- origin
- destination
- departure time
- arrival time

Schedule data are stored in vectors/matrices of information, where a flight is uniquely referenced by the row index into the Flight Characteristic vectors.

Thus a flight occurrence is uniquely referenced by the pair (date, row index).

2. Routing Data

The routings then are sequential lists of flight occurrences. Each routing is referenced by a number from one to the maximum number of routings, a variable value. This reference number also indexes a matrix containing information on the aircraft assigned to the routings. Aircraft information includes tail number, type of aircraft, configuration, and number of seats. This information was set up and used in establishing the initial set of aircraft routings.

3. Message Data

Messages can be added to the flight occurrences. Two structures are maintained for this purpose. The first is a list of flight occurrences that have messages associated to

them and the second contains the corresponding messages.

4.2 Building a Display

The concepts and process for constructing a display are described below.

1. Determine the day and time interval that the user wishes to view.
2. From the above information establish a date range for viewing.
3. Find the set of flights for each routing that underlie this date range, add the adjacent flight at each end of the range.
4. Calculate the locations for each arrival and departure if they were to be placed on a tape calibrated according to the time interval selected.
5. The date range determines the left-most and right-most column of the tape that will be part of the display. Compare the arrival and departure locations against these values and build the display based on those that fall within the range.
6. Send this display to the screen adjusting for any user specifications.

4.3 Referencing a Display

The usual means for the user to reference the display

is with the cursor. The position of the cursor can be easily translated back to a position on the imaginary underlying tape structure, and back to time if needed. The row position immediately gives the routing, and the column position indicates which flight by comparing it against the arrival and departure locations temporarily saved for the current display.

In general, each function provided references the display, makes the appropriate changes to the data, and either redisplays the current information, or rebuilds the display for a new range of information. See Appendix B for a more detailed description of the interactive system.

CHAPTER 5

AREAS OF FURTHER WORK

Further work in the area of aircraft scheduling might involve the following list of capabilities :

1. Multi-user system.

Presently, the system is for a single-user. Operations Planning will use the system initially as the system is developed, but ultimately what is needed is a multi-user system for Maintenance Planning, Operations Control and Operations Planning, who are all involved with the different aspects of aircraft routing.

Further tools would have to be added to meet the specific needs of each of these areas. For instance, Maintenance would need to see flying hour counts for the aircraft.

The output of this system would also be beneficial to many other areas of the airline, such as Payload Control, or Crew Scheduling.

2. Global Changes.

Presently, all changes made to the routings and schedule can only be done on an individual basis. It would be beneficial, in terms of the user-effort involved, to be able to make changes effective throughout the period or a

restricted set of circumstances.

3. Storing of Alternatives

The capability of storing the different scenarios developed for later reference would be a major asset to the "what-if" process.

4. Identification of Aircraft Reroutings.

The users have expressed the need for the computer to answer the following questions:

- What different ways can the aircraft be rerouted in order to position a specific aircraft at a given time and place?
- What exchanges are necessary in order to bring the aircraft back to their cycling patterns?

5. Statistics Generation.

Typical statistics that might be beneficial are:

- total aircraft flying hours
- weekly aircraft flying hours
- flying hours remaining to next maintenance check
- aircraft utilization (comparison of flying hours to downtime hours)

6. Report Generation.

Presently, changes made to the data base are logged and can be output to a file. It would be beneficial to develop a reporting system for these changes and for a statistic update.

7. Hardcopy Facility.

Presently, the displays can be printed, but without the color bars. They are difficult to read for this reason. This facility should be further developed. As well, options for printing selected information could be added.

8. Aircraft Rotations Modelling.

It would be possible to use the present and future system capabilities for the development of aircraft rotations. (See Lebeuf, 1985) Operations research models could be added as further tools for user support. Etshmaier and Mathaisel (1984) discuss the models that have been used by other airlines. These include assignment models, network flow models, dynamic programming, branch and bound, and various heuristic methods. (See also Holst and Sorensen, 1984; Kayukawa, 1983)

The aircraft rotations would also provide input to many other systems at CP Air that presently require manual data entry of flight connections.

CHAPTER 6

CONCLUSION

6.1 Summary

This project can be summarized with the following remarks:

1. The DSS approach to aircraft routing and dynamic scheduling is very appropriate given the changing circumstances and constraints. The system allows the user to make decisions based on his knowledge and experience, and attempts to support him in this process.

   The system has focused on the key aspects of highlighting downtime periods and exchange points, and key functions for modifying the information. One of its main strengths lies in the simplicity of approach and use.

2. The system is a starting point in an area that has long needed some helpful automated tools. It will save time and labor in charting, experimenting and finalizing changes, aspects that have been burdensome with present approach.

   More work can be done in striking a better balance between man and machine. Presently the balance is heavy

on the human side, and more capabilities should be added to support the work.

Beyond this there are many opportunities for growth and development into such areas as schedule planning and maintenance planning.

6.2 Stage of Implementation

Operations Control have affirmed the usefulness of the tools in discussions and demonstrations, and some options, such as the message facility, were added at their request. They have been eager to see the system put into practice and the project is just now in the stages of system testing and user-training. It will be used in parallel with the work in Operations Planning this fall. This will allow for a more thorough evaluation, and appropriate modifications and enhancements can be made.

BIBLIOGRAPHY

1. Benbasat, I. and Y. Wand. "A Dialogue Generator and Its Use in DSS Design", Information and Management 5, 1982, pp. 231-241.

2. Benbasat, I. and Y. Wand. "A Structured Approach to Designing Human/Computer Dialogues", Working Paper No. 835, 1982.

3. Etschmaier, M. M. and D. Mathaisel."Aircraft Scheduling: the State of the Art", Proc. of XXIV AGIFORS Symp., France, 1984.

4. Gaines, B. R. "The Technology of Interaction - Dialogue Programming Rules", Int. J. Man-Machine Studies 14, 1981, pp. 133-150.

5. Holst, O. and B. Sorensen. "Combined Scheduling and Maintenance Planning for an Aircraft Fleet", Operations Research, 1984.

6. Kayukawa, K. "ARAJIN (Aircraft Routing and Automatically Job Integrating at Narita Base Station) System", Proc. of XXIII AGIFORS Symp., Tennessee, 1983.

7. Keen, P. G., and M. S. Morton. Decision Support Systems An Organizational Perspective, Addison-Wesley Publishing Co., Reading, Mass., 1978.

8. Lebeuf, D. "L'Allocation des Appareils pour un Horaire Aerien : Une Approche Interactive-Graphique", M.Sc. Thesis, University of Montreal, Centre for Transportation Research, Montreal, 1985.

9. Lembersky, M.R., and U. H. Chi. "'Decision Simulators' Speed Implementation and Improve Operations", Interfaces 14, 1984, pp. 1-15.

10. Sprague, R. H. and E. D. Carlson. Building Effective Decision Support Systems, Prentice-Hall Inc., New Jersey, 1982.

APPENDIX A

PRESENT APPROACH TO AIRCRAFT CYCLING AND SUBSTITUTIONS

A.1 Initialization of Aircraft Routings

A.1.1 Preparation of Charts

The entire schedule for the six-month period is visually displayed on a master copy of the Aircraft Utilization Chart, a grid of time versus type of route, to show the location of the aircraft at any given time. The chart covers one week from Sunday to Saturday in Greenwich Mean Time (GMT), and the routes are categorized by aircraft type and district. The organization of the charts is planned for each period in a way that will be most beneficial for the planner. The charts must then be drawn, and the flights placed according to route categories chosen.

Each flight is displayed as a horizontal bar indicating its GMT times, city codes, flight number, and dates for which the flight is operative.

The chart is then duplicated and each week is individualized by dating the days and whiting out the flights which are inoperative for that week.

A.1.2 Establish Operational Cycles

The next step in the aircraft routing process is to develop operational cycles of flights that will be used as a pattern to route aircraft for the period. Using the basic cycling charts from the schedule development process, as seen in Figure A.1, aircraft exchange points are found so that the aircraft can be rotated onto the various cycles that allow for its type and seat configuration. If a cycle only allows for one particular aircraft then it is treated in isolation.

The two major reasons why aircraft are rotated on the cycles are:

1. Balance of flying hours. The major maintenance checks have been scheduled based on average flying hours, and in general the weekly cycling patterns are not equal in flying hours.

2. Regular opportunities for minor maintenance. Minor maintenance periods have been scheduled onto only some of the weekly cycling patterns so rotating the equipment allows each to come in periodically. In general, for the wide-body equipment the requirement is that each come in for a 14-hour maintenance period every two weeks.

In general, this step in the process requires reproducing the utilization charts again and establishing several cycling patterns until one is decided upon.

A.1.3 Assigning Aircraft Tail Numbers

In order to initialize the assignment of aircraft to routes, the new schedule must be "phased-in", i.e., the first flights of the new period adjusted so there is a smooth transition from the last scheduled flights of the previous period. Usually, several options for "phasing-in" the new schedule are developed and presented to Payload Control for a decision to be made. Other than the "phasing-in" decisions, aircraft are assigned arbitrarily.

The next step is to go through the schedule, sequentially assigning according to the operational cycling patterns developed, and adjusting for minor route restrictions and major maintenance checks. (See Figure A.2 for maintenance schedule.) This will involve aircraft substitutions where necessary. Again these cases are presented to other groups such as Payload Control for a decision to be made.

The aircraft assignments are performed by linking the bars on the charts with colored lines, matching the tail numbers to the lines at the start and finish of each week. Part of the Utilization chart is illustrated in Figure A.3.

The above initialization process takes several weeks of manual work.

A.2 Handling Requests for Extra Usage

The above routing of the aircraft provides up-to-date visual availability of the aircraft downtime. This is necessary in order to provide equipment for all extra usage required during the life of the schedule. Examples of extra usage being extra sections, charters, special stops, promotional flights, pilot training, cabin attendant training, advertising requirements, etc.

The first step upon initially receiving a request is to identify how much time is needed. It then must be evaluated whether or not an aircraft is available for that length of time or can be made available by manipulating the routings to produce a larger downtime period. If an aircraft is available, this must be confirmed by maintenance. The cycling requirements and flight itinerary are identified for the initial request.

This information then goes back to the Sales Department for confirmation, and as well to each department. If there are any problems that would prohibit this request, then that department would notify Operations Planning, who would then try to make adjustments. When the request has been confirmed, a flight order is prepared and distributed. At this point the cycling requirements must be rechecked, and

appropriate changes are made to the routings.

A.3 Co-ordinating/Reflecting Changes

Operations Planning is the source of the planned aircraft routings, and thus any changes must be co-ordinated with them.

As mentioned earlier, Operations Control is responsible for handling all short-term changes, in particular emergency situations that arise in daily operations. An example is when a plane has an engine breakdown and is unable to perform the next flight. Their approach is to find a solution that solves the immediate problem. Operations Planning will adjust the books to reflect that change and the consequences of it. If the changes have affected the routings beyond the next ten day period, Operations Planning must bring the aircraft back to cycle.

The narrow-body aircraft are routed by Maintenance Planning, and there are generally no problems involved. This is because the aircraft return to Vancouver nightly, or at most every three nights, so they can be rerouted at any point to suit maintenance purposes.

However, on occasions where Operations Planning is trying to extend downtime for extra flying, they will change the routing to properly position the aircraft, and confirm this with Maintenance.

Often Maintenance Planning will inform Operations Planning of necessary changes to the schedule and routings to accommodate for changes to the maintenance plan. If these are not satisfactory, then Operations Planning will suggest alternate solutions.

Thus, Operations Planning acts as the key focal point for decisions dealing with aircraft usage. They are often not the decision-maker, but rather a decision support system themselves in providing information and suggested solutions to others.

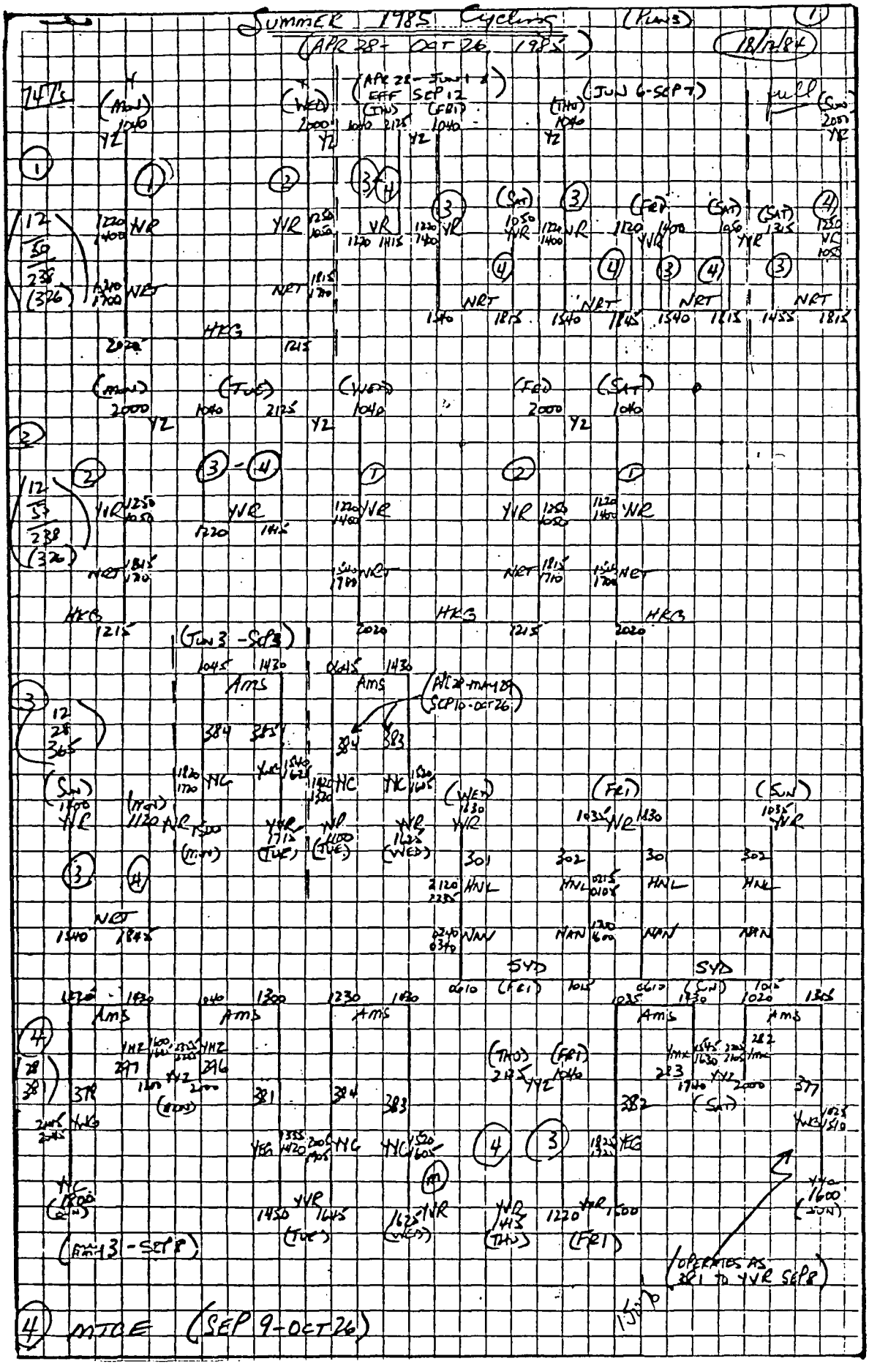

Figure A.1 Example of Cycling Charts

MAINTENANCE CHECK SCHEDULE

1985 MAR 28 1985

CP Air

Figure A.2 Example of Maintenance Schedule

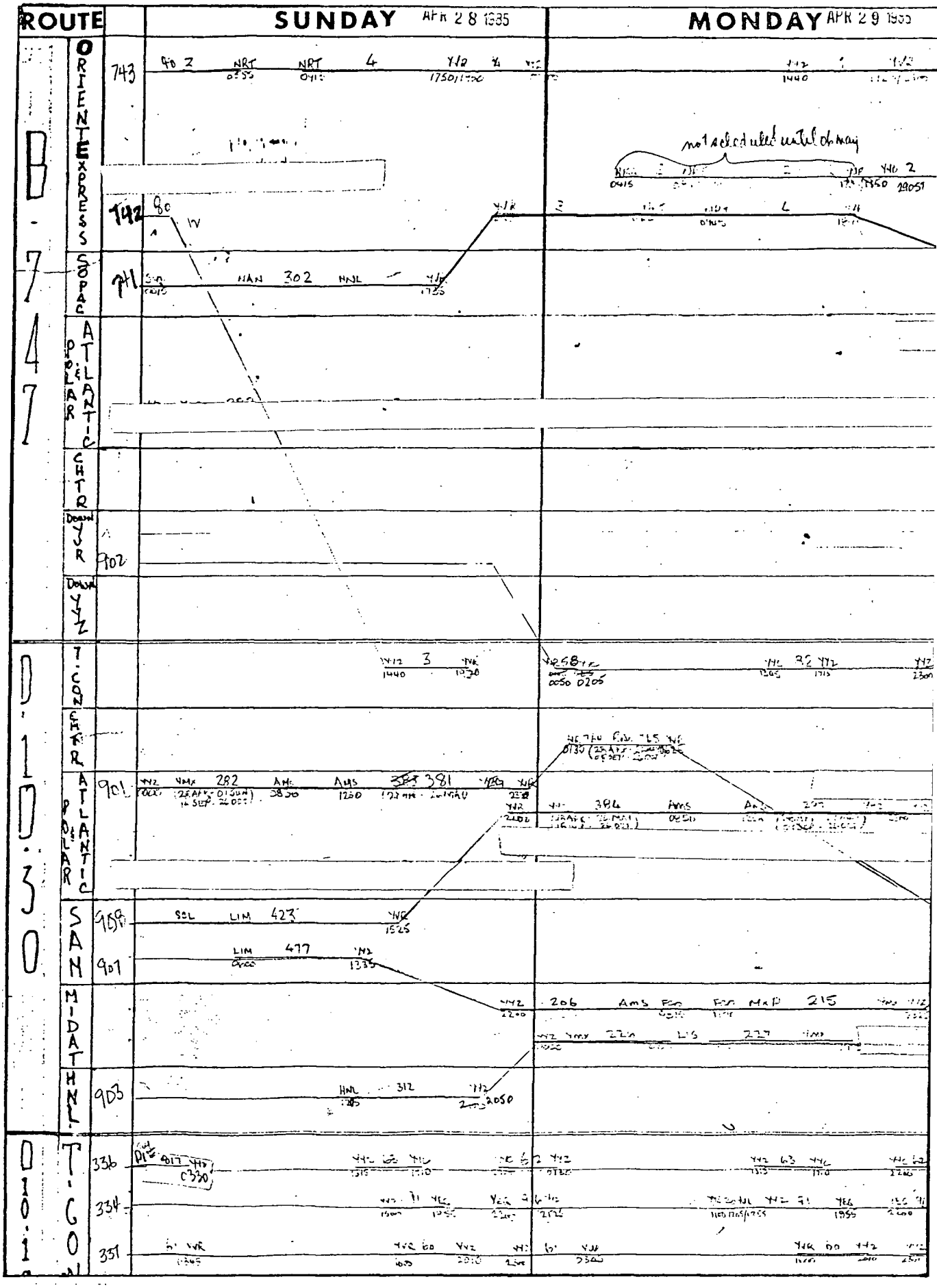

Figure A.3 Example of Aircraft Utilization Charts

APPENDIX B

TECHNICAL DESCRIPTION

B.1 General Overview

The system is separated into two parts - the first is to obtain an initial set of routings for the period, and the second is an interactive graphic system to display and handle changes to the schedule and routing information.

B.2 Initialization of Routings

B.2.1 Overview

The purpose of the aircraft routing programs is to obtain an initial set of routings that satisfy basic schedule requirements. These can be modified using the capabilities of the interactive system to incorporate all schedule and maintenance requirements, in particular any qualitative considerations.

A First-In-First-Out (FIFO) algorithm already available, was modified and used for routing the aircraft on those flights that match on type and if possible on seating. If there is no available aircraft of the correct type, then a new aircraft is generated and treated with low priority to prevent further flights from being unnecessarily allocated to it. The user must later reallocate this flight where he sees best.

B.2.2 Function Overview

GETOSSKED - picks up the current schedule

BUILDACTRACE - builds a matrix that will trace the aircraft routings

USESCHED - sets up the flight information to be used for the routing program

ACROUTE - performs the FIFO aircraft routing algorithm

MAKROUTS - pulls out the routings in a form readable by interactive graphic system

REFORM - converts the flight information into a form readable by interactive graphic system

B.23 Function and Variable Description

GETOSSKED
Input Variables:
- Current Season e.g. 'sked.w85' for winter '85 schedule
Output Variables:
- SCHED schedule matrix
- ACTYPES list of aircraft types in schedule
- ACCONFIGS list of flight configurations from schedule

BUILDACTRACE
Input Variables:
- ACINFO description of fleet in terms of tail numbers, type, current configuration, number of seats
- TYPES list of aircraft types to be routed
Output Variables:
- ACTRACE initial position of aircraft in fleet

USESCHED
Input Variables:
- SCHED schedule matrix
- NUMDAYS number of days for routing
- TYPES aircraft types to be routed
- SEATS total number of seats corresponding to ACCONFIGS
Output Variables:
- GMTSKED information about flights to be allocated to aircraft

ACROUTE
Input Variables:
- GMTSKED flight information
- ACTRACE aircraft trace information
Output Variables:
- GMTSKD revised flight information with aircraft assignments
- ACTRACE final position of aircraft needed to operate schedule

MAKROUTS
Input Variables:
- ACTRACE information about all aircraft needed to operate schedule
- GMTSKD assigned flights
Output Variables:
- MNUM maximum number of routings
- R1..RMNUM Aircraft Routings

REFORM
Input Variables:
- SCHED schedule matrix in APL character format
Output Variables:
- SCHEDDATA schedule information in numeric format
  - FLTNO flight numbers
  - LEGS number of flight sectors

- START starting index of leg information
  - ORIG originating cities
  - DEST destination cities
  - DEP departure times
  - ARR arrival times
- DATE date range for routings

B.3 Interactive Graphic System

B.3.1 Overview

This system starts with a schedule and an initial set of routings and then focuses on the dynamic modifications to the schedule and routings. Its purpose is to present in a clear and usable way a set of tools for allowing the user to make changes.

The approach of Sprague and Carlson (1982) to DSS involves the following elements:

1. Representations
   - illustrations to conceptualize and communicate the problem
2. Operations
   - functions to analyze and manipulate information
3. Memory Aids
   - abilities for recalling information
4. Control Aids
   - tools to control the flow of the system

This is called the ROMC approach.

These elements are to be built with the capabilities provided by the DSS Generator and the supporting DSS Tools. The resulting system is called the Specific DSS that will be applied to the given task.

This application was chosen to be developed on CP Air's IBM 3033N using the VM (Virtual Machine) operating system. The main advantage to using the VM system is that there are hardware and software capabilities available that would serve as DSS Generator and Tools. The IBM 3279 terminal has been used because of its larger screen dimension of 32 lines and its color graphic capabilities. Application Prototype Environment (APE) for APL environments, has been used in developing the interactive system. This software package allows for relatively quick development of "prototype" decision support systems involving color graphics, easy use of menu and program function keys, and a "windowing" effect of display information. All these capabilities support the ROMC approach to DSS.

B.3.2 Function Overview

There are four major function groups defined to be:

1. DISPLAY functions that build the display

2. WINDOW functions that create the "windowing" effect of the display

3. VIEW functions that adjust the view for different ways of displaying the same information

4. UPDATE functions that allow for modifications to the data base

Within each function group the major functions are described.

1. DISPLAY

BUILDINFO- initializes the display information matrix on which flights will be displayed

BUILDVARS - builds the display variables

OUTPUTVARS - sends the variables to the screen and awaits for user to perform functions

2. WINDOW

PFEVAL0 - evaluates the first set of program function keys that mainly deal with the windowing effect of the display such as scrolling and a zoom/wide facility

3. VIEW

PFEVAL1 - evaluates the second set of program function keys that mainly deal with adjusting the view of current information

4. UPDATE

PFEVAL2 - evaluates the third set of program function keys that deal with updating of the data base, in terms of messages, rerouting aircraft, and updating flight information

B.3.3 Function and Variable Description

1. DISPLAY

BUILDINFO
Input Variables:
- IDAY date requested
- DNO display number (time interval) requested
Output Variables:
- LPUP left day to pick up for display
- RPUP right day to pick up for display
- MIN minimum column of display
- MAX maximum column of display
- CRANGE current range of information
- CINFO range of current information matrix
  - CINFO(i;1) starting location of current flights for ith routing

- CINFO(i;2) number of current flights for ith routing
- DINFO display information matrix

BUILDVARS
Input Variables:
- IDAY, DNO, DINFO, MIN, MAX
Output Variables:
- DISP display of routings
- DISP CA color attribute matrix corresponding to DISP
- ACNO aircraft tail numbers
- ACNO CA color attribute matrix corresponding to ACNO
- DATE timeline
- ALi arrival locations for ith routing
- DLi departure locations for ith routing

OUTPUTVARS
Input Variables:
- DISP, ACNO, DATE
Output Variables:
- PFCHOICE program function key selected by user

All functions from the groups PFEVAL0, PFEVAL1, PFEVAL2 are based on using program function keys and follow a set of the following phases: (see Gaines, 1981; Benbasat and Wand, 1980,1982)

1. Prompt - the user is prompted for input

2. Input - the user provides input either by using the cursor, or typing in the information requested

3. Action - the system takes action based on the input and confirms the action with an output message

4. Check - the system checks the input request and reports any error messages and either indicates that the function has been terminated or awaits more input from the user

5. Next - the system indicates that it is waiting for the next input from the user

6. Signal - the system performs or aborts the function upon receiving the signal from the user

7. Help - eventually a help option will be available with each function