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WAYS AND POSSIBILITIES OF PREPARING DATA AT AIRPORT FOR BALANCE IN CHECK-IN AND CHECK-OUT CONNECTED WITH AIRCRAFT BALANCE COMPUTER

SUMMARY

This paper deals with the criteria and requirements in developing general autonomous software related to handling aircraft at the airport. It gives an overview of almost all the influencing factors which are relevant to "processing" an aircraft both upon arrival as well as on departure. It gives a brief description of the conventional balancing method which is being used, of the latest advancement in the field, and it offers a concrete suggestion for improving the reliability of criteria and results in aircraft handling.

The main idea of this initial work is to unify all the necessary activities and to register them by one computer, from landing until take-off, including computer communication with other airports and companies. Currently, the programs of certain air companies are being used and they have produced individual software in co-operation with the manufacturers only for certain types of aircraft that are currently employed by them.

Since the range of aircraft types landing at airports is growing, there is the need to find a universal program which can calculate the balance chart for each aircraft based, of course, on the manufacturer-supplied design data.

KEY WORDS

aircraft balancing, computer, aircraft

INTRODUCTION

The development of aircraft and aircraft technology have recently been under the influence of contradictory requirements - on the one hand, the aircraft should provide great efficiency and performance along with the least adverse impact on the environment (low levels of exhaust emissions, noise and waste), and on the other hand, the reliability and safety would have to be increased. These improvements should be accompanied by low production and maintenance costs.

The parameter within this field, which can be improved by every airport is the technology of passenger handling, especially with regard to safety of the subsequent flight, which includes good balancing and technical equipping of the aircraft.

Roughly, the technology at an airport can be divided into the technical part, dealing with equipping and servicing the aircraft and the part dealing with passenger and cargo handling. These activities are in fact, at the moment, separated, and are being carried out separately by single operation services at the airport.

The recordings of these procedures are unified only in the official form used for balancing the aircraft which is filled in directly prior to the aircraft take-off, and which contains only those data that refer to changes in cargo, people and fuel, whereas the technical details regarding servicing and other operations performed on the aircraft are kept by the technical services.

This leads to the conclusion that this method of keeping the register (except in special cases) does not provide safe aircraft handling, since there are no data on the technical condition of an aircraft arriving into the airport, and therefore no guarantee for its technical condition on take-off.

The performance card, in the form of a servicing card and other technical documentation is kept exclusively by the air company which owns the aircraft and provides the transportation service, in agreement with the manufacturer, according to the set international regulations defined by law. In case of an accident the air-company is responsible for failures.

The aim of this paper is to unify all the activities involving the aircraft during its stay at the airport and their registration by the computer network connected not only within one airport but to all other airports in contact. The paper deals for the moment only with the new method of aircraft balancing. In this way, all the data about a certain aircraft would be available to every airport of its landing, with all the changes during its operation.

The data on the number of passengers, weight and distribution of cargo, as well as condition of the fuel tanks would be known before landing. Information would be available about the passengers in transit, those getting off, about baggage that has to proceed to next destination, and which baggage will reduce the load of the aircraft. Figure (1) presents the schematic function of such a system:

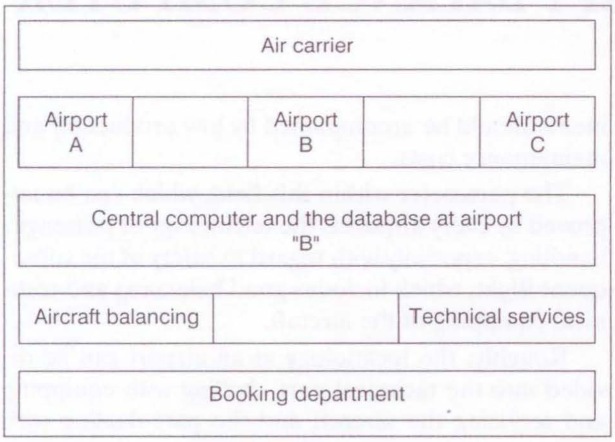

Figure 1

First, we must sort the data to be able to use them in the autonomous universal program (algorithm) for aircraft balancing which would form a part of the comprehensive program set as the objective of this work.

1. THE PURPOSE OF AIRCRAFT BALANCING

The aircraft centre means the position of the aircraft centre of gravity expressed in the percentage of MAC - Mean Aerodynamic Chord. MAC equals the chord of an imaginary rectangular wing having the same surface area as the considered wing, and subjected to the same momentum due to aerodynamic forces. The aircraft manufacturers supply the value for the mean aerodynamic chord for every type of aircraft, and they also provide information on its position using the co-ordinate system. The co-ordinate origin can be at various positions, as necessary. Its most logical position is in the nose of the aircraft, so that the z-y plane is the tangent plane to the aircraft nose. In some aircraft this plane is positioned at the beginning of the cockpit windscreen, and the more recent aircraft types have this plane in front of the aircraft nose.

In order to avoid the negative values of the fuselage cross-section and to allow nose modifications, system c) is mainly accepted at present. In order to locate the MAC position one should know the point on the x-axis accommodating the leading edge of the mean aerodynamic chord. This value is also determined by the manufacturer.

The handling services use the following elements:

I. registration code of the aircraft that needs to be balanced
II. version in which the aircraft will fly
III. number of the crew members in the cockpit and in the cabin
IV. kinds of passenger service planned for the particular flight
V. data on any special equipment loaded on the plane
VI. the amount of fuel carried by the aircraft, both the amount of take-off fuel and the amount of trip fuel
VII. the number of passengers taking the flight, for every airport of landing according to the specification:
    A. adults
    B. children (2 - 12 years)
    C. infants;

these passengers need to be divided into classes they fly (*economy and business class*);

I. the number of passengers in transit
II. the amount of cargo, post and luggage for every airport

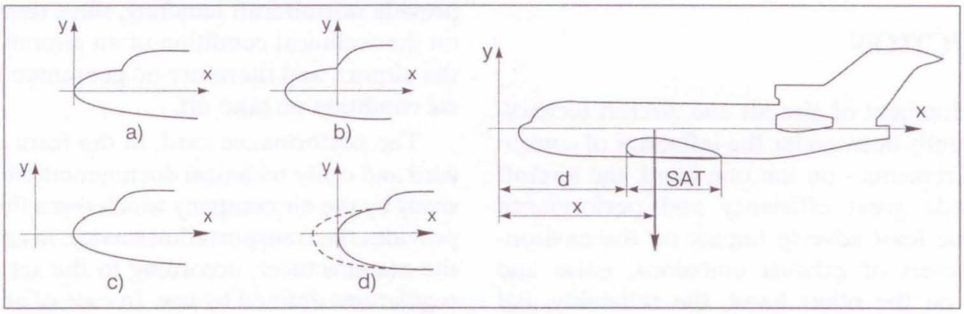

Figure 2

III. the amount of cargo, post and luggage in transit for every airport
IV. the weight of personal luggage taken into the cabin
V. the last minute changes

The remaining data needed for balancing are taken from the manual. These additional data include:

I. the basic weight of the aircraft
II. the basic aircraft index (index of the dry aircraft) prepared for the flight
III. maximum take-off weight (operational or design weight)
IV. maximum landing weight (operational or design weight)
V. maximum design weight with zero wing fuel in flight.

Based on the above elements, the handling services balance the aircraft and give instructions to the staff at the platform about the way the aircraft needs to be loaded.

Aircraft Weights (Necessary Data And Terminology)
Manufacturer's Empty Weight – MEW
Standard Basic Empty Weight – SBEW SBEW = MEW + Standard Items
Basic Empty Weight – BEW BEW = SBEW + SIV
Operational Items
Basic Weight – BW BW = BEW + Standard Operational Items
Operational Empty Weight – OEW OEW = BW + Variable Operational Items
Dry Operational Weight – DOW DOW = OEW
Maximum Design Weights
Maximum Zero Wingfuel Weight – MZWFW - MZFW
Maximum Design Landing Weight – MLW
Maximum Design Take-Off Weight – MT/OW
Maximum Design Taxi Weight – MTW
Payload – P/L
P/Lmax = MZWFW - OEW
Operational Weight – OW
Total Fuel Capacity – TFC
OW = OEW + T/O FUEL

Some of the mentioned weights have several aspects. Thus e.g. when an aircraft is said to have take-off weight *x*, this can mean several things: *x* may be design, operational or actual weight.

Methods of Balancing

Classical Method

As known from static, the determining of the aircraft centre of weight is in fact the summing up of the following parallel forces:

a) basic weight
b) weight of the crew
c) weight of the buffet
d) weight of the fuel
e) weight of the passengers (divided according to classes or aircraft zones)
f) weight of cargo, post, and luggage (separately for each belly compartment)

The sum of all the forces gives the weight at take-off, and the sum of moment divided by T/OW gives the position of the weight along the x-axis.

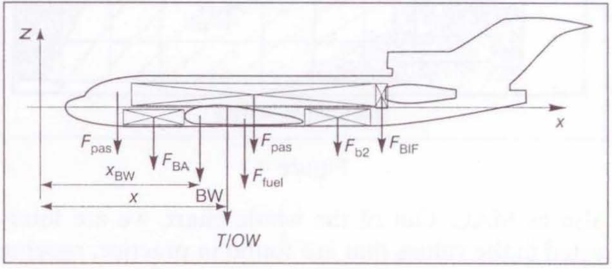

Figure 3

Thus My = ΣFi*xi and T/OW = ΣFi*xi/ΣFi. Knowing X the aircraft centre can be determined

$$\%MAC = (X-d)*100/MAC$$

where:

d – is the distance of the MAC leading edge from the co-ordinate origin,
X – is the distance of the aircraft centre of gravity from the MAC leading edge.

Graphical Method (Balance Chart)

Unlike the analytical method, the procedure for determining the position of the aircraft centre involves drawing straight lines using a ruler on a certain form called the Balance Chart. For better understanding of this method, it is necessary to know the diagram in the bottom part of the balance chart. (Figure 4)

In order to be able to determine the aircraft centre, the moment of the force of gravity of the aircraft and the weight itself need to be known, so that M = X*W where M is the momentum of aircraft weight, X is the distance of the aircraft force of gravity from the adopted lateral axis, and W is the weight of the aircraft.

The direct proportional dependence of the momentum on the weight is presented in Figure 5. Each line stands for the change of the momentum, with the increase in weight W. The value X can be expressed

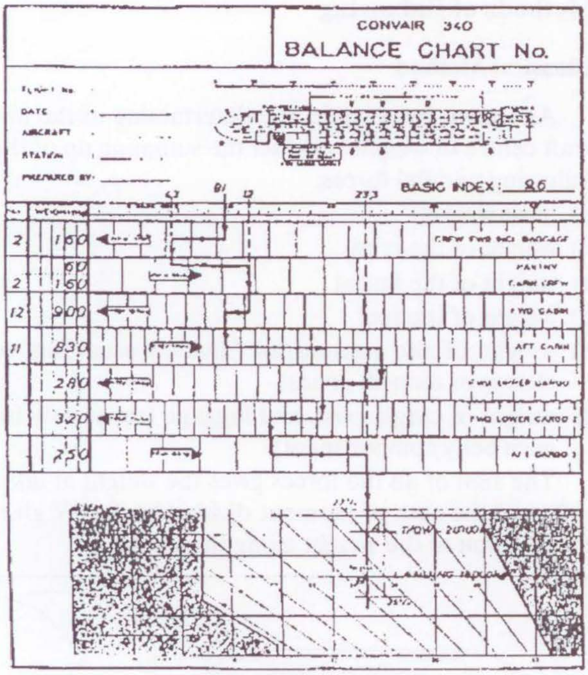

Diagram M = f(W)

Figure 4

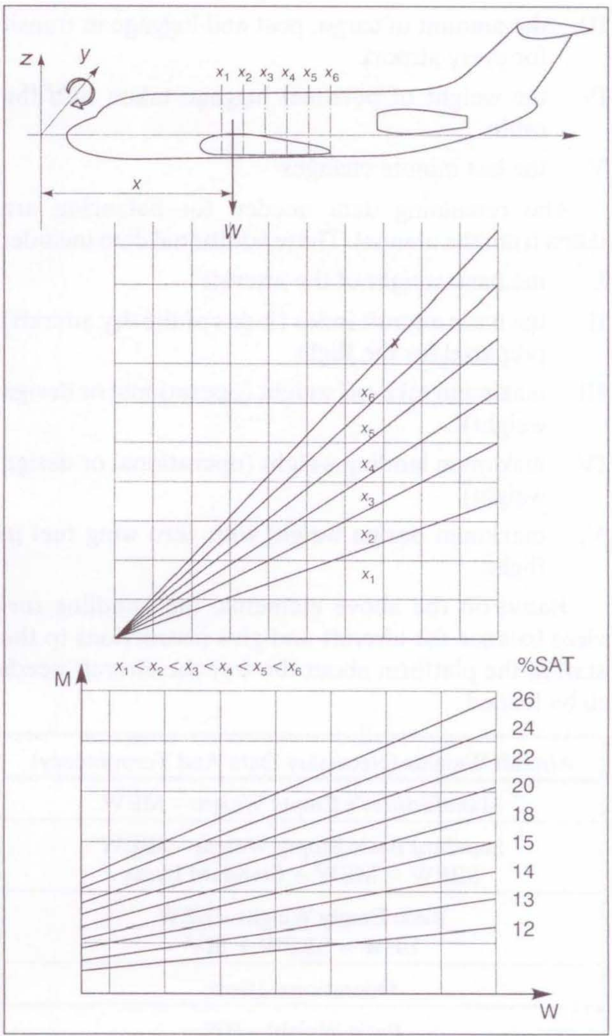

Figure 5

also as MAC. Out of the whole chart, we are interested in the values that are found in practice, ranging from W_{min} (somewhat below BW) up to MT/OW.

Also, for the balancing purposes it is interesting to consider the part of the chart from the extreme front allowed centre to the rear allowed centre. The centre of gravity will have to be within this area. Figure 4 shows a condition for a certain weight (e.g. BW) and a certain position of the centre of gravity which defines the point A (BW, MAC). It is interesting to consider how the centre of gravity and the aircraft centre defined by point A will change if we add or subtract weight W at a certain point C:

$$Wu = BW + \Delta W$$

$$M = M_{BW} + c^{*}\Delta W = M_{BW} + \Delta M$$

M_{BW} is the momentum of the basic aircraft weight, and ΔM is the change of momentum due to additional weight ΔW.

The Effect of Selecting Lateral Axis on the Chart M=f(W)

For the axis set somewhere around the aircraft nose, the momentum of all cargo, as well as the aircraft itself is always positive and of large values. If we moved the axis closer to the centre of gravity, the values of the momenta would be reduced. Further moving of the axis would result also in negative values of the momentum.

The best position is within MAC, which gives the minimal values of the momentum, and the chart itself is the most suitable because of its shape.

The Balance Chart form includes a chart, but the difference is that the weight axis is set vertically, and the momentum axis is horizontal. Sometimes the line network of the constant momentum value is left out, thus obtaining a clearer chart.

Balancing the Aircraft by Using the Chart M=f(W)

In order to balance the aircraft using the chart, it is necessary to know the starting condition of the aircraft given by co-ordinates of the point A (BW, %MAC). Then, knowing weights of all the cargo ΔW_1 ... ΔW_5 which is being loaded, the changes ΔM_1 ... ΔM_5 are calculated and points B, C, D, E and F obtained one after the other.

Point F represents also the condition of the loaded aircraft. This method of balancing reminds of the summing of vectors, Figure 7.

The rule that the sum of vectors does not depend on the sequence of summing holds here as well, and in aircraft balancing terminology this means that the air-

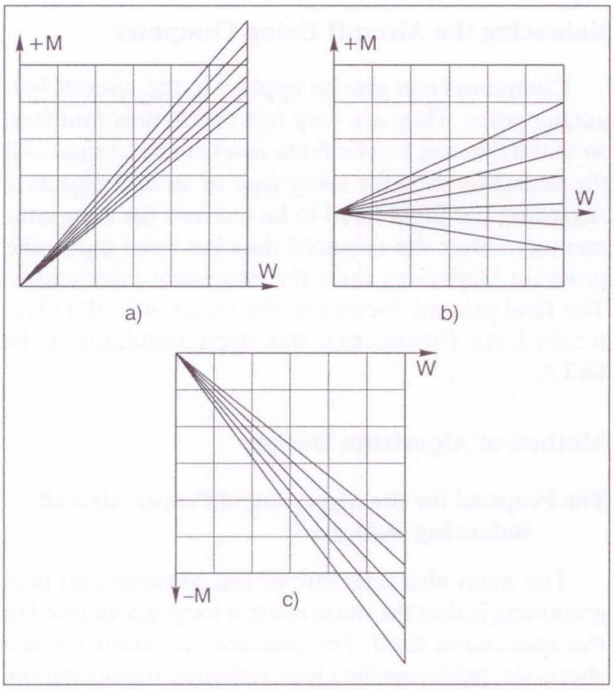

Figure 6

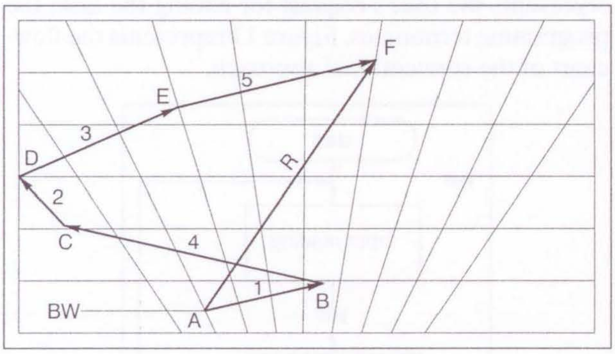

Figure 7

craft condition upon loading does not depend on the sequence of loading, but on:

a) condition of the aircraft prior to loading of cargo (the starting point),
b) loading position of a certain cargo.

Every vector of change may be divided into two components: the horizontal one which indicates the change of momentum, e.g. ΔM_1, and the vertical one which represents the change of the aircraft weight, e.g. $\Delta W_{1.}$ In order to enter the vectors of change into the chart M=f(W) more easily, a transparent overlay may be made, valid only for a certain type of aircraft and its appropriate chart.

The following cargo loading spaces are defined on this model:

I. 1st class passengers
II. tourist class passengers
III. front belly compartment
IV. aft belly compartment
V. fuel (Figure 8)

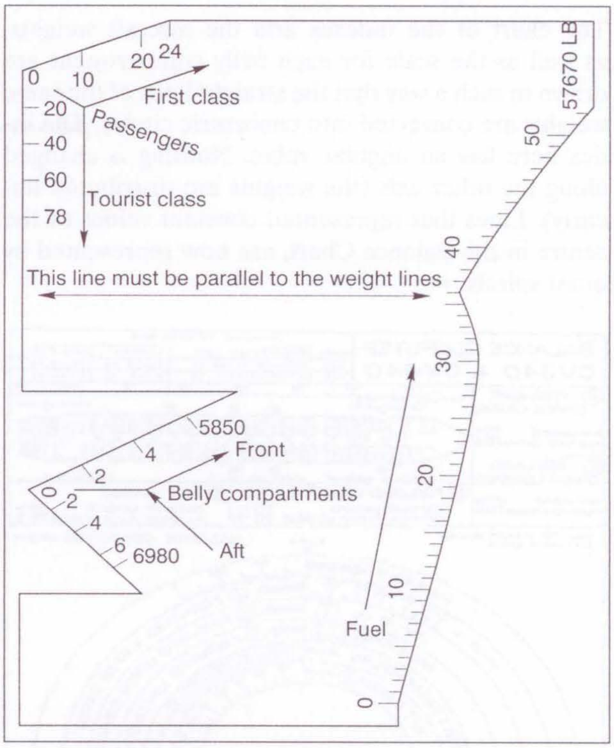

Figure 8

There is a line on the overlay that has to be parallel to the weight lines when individual vectors are drawn onto it, thus insuring the accuracy of the angles α, β, γ, etc.

For every space on the overlay there is a scale at a certain angle to the lines of constant weight. Every scale is marked by weights in kg or lbs from 0 to the capacity of the given space.

The passenger scale is drawn in such a way that it reads the number of passengers. In order to obtain point B from the starting point A, which is obtained by loading the cargo into the front belly compartment, the overlay is superimposed so that the line is parallel to the lines of constant weight in the chart M=f(W). Then the line is drawn on the scale of the front belly compartment to the point which represents the weight loaded into the front belly compartment. Thus point B is obtained. The procedure is repeated until data on all cargoes are entered. In this way the balancing of the aircraft has changed from multiplying and dividing a huge number of values using the classical method into drawing using overlays. The accuracy of this method is within the allowed limits of the aircraft centre.

The Balance Computer Method

Further improvement of the aircraft balancing has led to the development of the so-called Balance Computer. This method uses the same way of balancing, except that it eliminates the need for rulers.

The chart of the indexes and the aircraft weights, as well as the scale for each belly compartment are drawn in such a way that the straight lines of the same weights are converted into concentric circles. The index here has an angular value. Nothing is changed along the other axis (the weights are distributed linearly). Lines that represented constant values of the centre in the Balance Chart, are now represented by quasi-spirals.

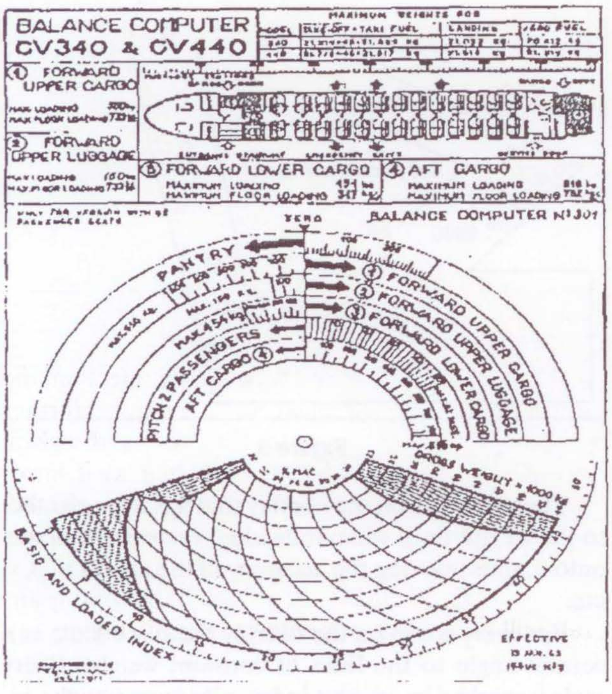

Figure 9

The design consists of a base and a transparent disc which is connected to the chart by a bolt whose axis matches the axis of drawing the chart. A red line is entered on the disc which passes through the disc centre and replaces the vertical lines drawn in the Balance Chart. Similarly to working with the Balance Chart, the initial value is the basic index BI, so that the red line on the transparent disc is placed on the value BI. Then one by one the values of cargo in the first compartment are entered on the scales, then the disc is rotated in the direction of the arrow, until the drawn line covers the value zero. Finally, when the disk stops in the position when the cargo in the last scale is loaded, the red line on the disc shows the value on the scale of index LI (value of TO/W and LW the aircraft centre in take-off and landing is obtained).

This method of balancing is simpler and faster compared to the Balance Chart, but no recorded document remains on land. The advantage of the Balance Computer is that the cargo may be distributed to the forward and aft belly compartments, so that the value of the aircraft centre is set in advance.

Balancing the Aircraft Using Computer

Computers can also be applied in the aircraft balancing poles. They are very fast and almost faultless, so that balancing can be done in a very short time. All the necessary data for every type of aircraft and data regarding the flight need to be fed into the computer memory. After the required data has been input, the program (software) does the necessary calculations. The final printed document, the result of EDP (Electronic Data Processing), has been standardised by IATA.

Method of Algorithm Design

The Proposal for the Algorithm of Proper Aircraft Balancing Software

The main characteristic of the conventional programming is that the main control loop is contained in the application itself. For instance, an editor reads a character, performs the given activities, reads then the next character, etc. Upon receiving a character which represents the user's request for ending the task, the programme terminates. Figure 13 represents the flowchart of the conventional approach.

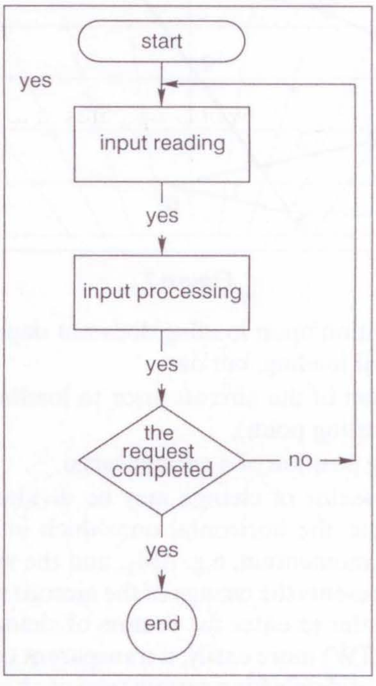

Figure 10

Unlike the conventional approach of interactive programming, this control structure is changed in notification based systems. The main control loop is contained in the *Notifier*, and not in the application. *Notifier* reads the events and calls various procedures which the application had previously associated with them using the *Notifier*. This control procedure is pre-

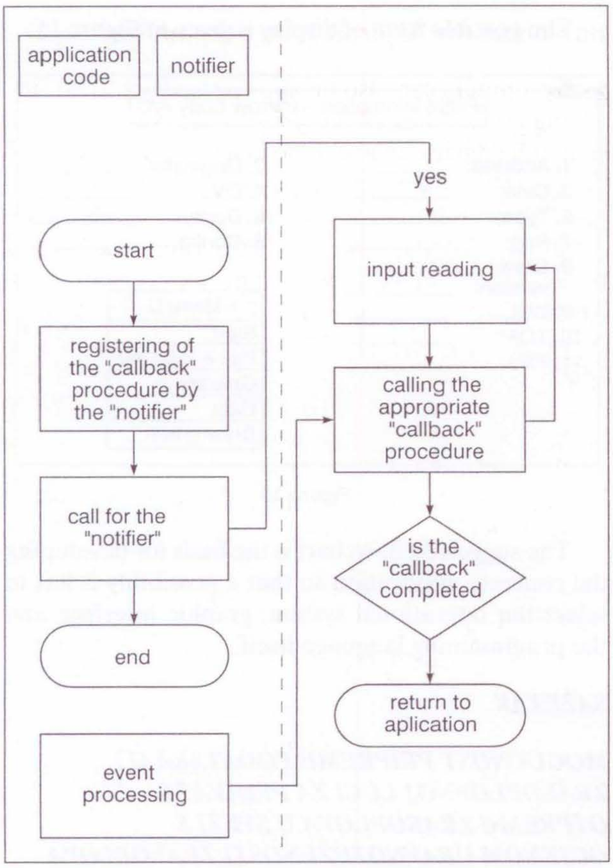

Figure 11

sented in Figure 11. *Notifier* operates in fact as a control entity within the user process.

Program Flowchart

Due to the way of using the aircraft balancing software, where constant user-computer interaction is necessary, notification-based approach is the most appropriate solution. From the point of view of the user this means that the application (program) starts with the initial window. Upon starting the application, the control of the process is taken over by the *Notifier*. It registers all the events, e.g. clicking of the mouse, or moving the cursor using the keyboard. After registering the event (selection of the option) the procedure (function) is called which has been previously associated with this event by the *Notifier*.

The program would consist of the main program and a range of functions. All the boxes and the objects in them would be created in the main program, and the functions would be called depending on the user. The application can be represented as a range of overlapping windows and sub-windows which appear on the screen according to the user's request. The flowchart of using the program is presented in Figure 12. Since drawing the flowchart in one piece would greatly exceed the format, it will be drawn in several phases.

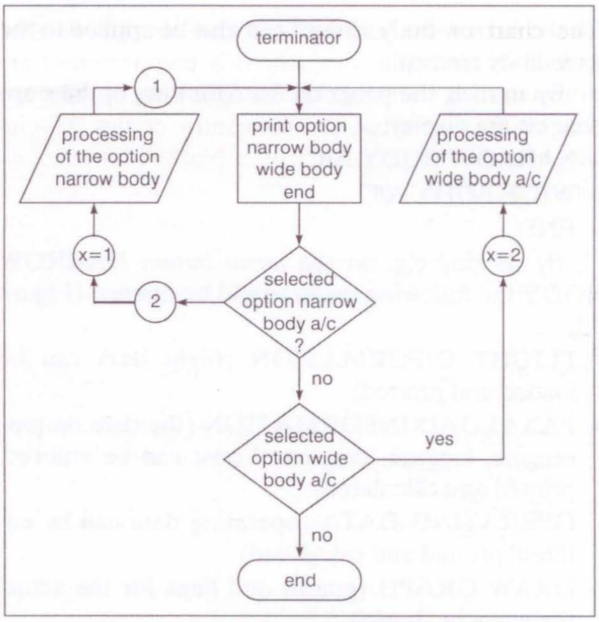

Figure 12

After having carried out the primary selection, the selected option is processed. In order to be further able to open the appropriate windows for the given type of aircraft, the global variable (e.g. x) is introduced as an identifier. If *narrow-body a/c* is selected, this variable will obtain value 1 (x=1), and when *wide-body a/c* is selected the variable is assigned value 2. The part of the flowchart related to narrow-body aircraft will be further presented in detail (Figure 13). The procedure is somewhat different for the wide-body aircraft, but the preliminary solution suggested

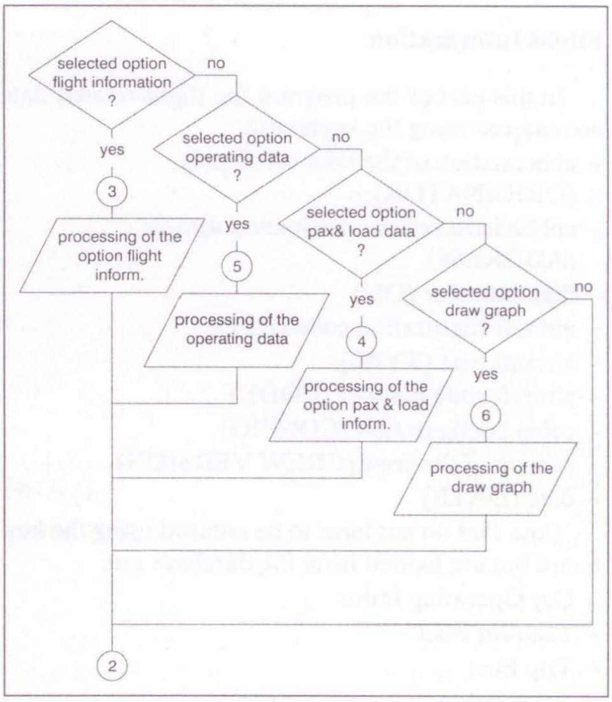

Figure 13

for the narrow-body aircraft can also be applied to the wide-body aircraft.

By starting the program the following options appear on the display:
- NARROW BODY A/C
- WIDE BODY A/C
- END.

By clicking e.g. on the *menu button* NARROW BODY the following menu would be opened (Figure 13)
- FLIGHT INFORMATION (flight data can be loaded and printed)
- PAX&LOAD INFORMATION (the data on passengers, luggage, cargo and post can be entered, printed and calculated)
- OPERATING DATA (operating data can be entered, printed and calculated)
- DRAW GRAPH (graphs and lines for the actual flight can be drawn)

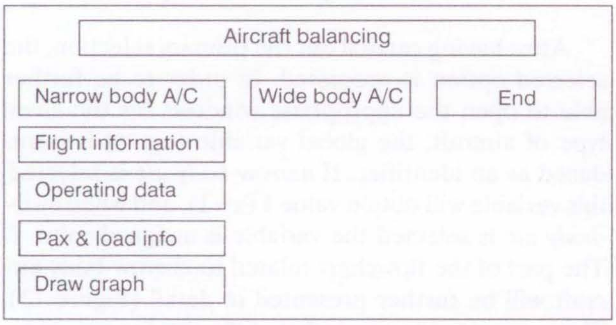

Figure 14

Flight Information

In this part of the program the flight-related data are entered using the keyboard:
- abbreviation of the take-off airport (ORIGINATOR)
- abbreviation of the destination airport (ADDRESS)
- flight number (OU)
- aircraft registration code (REG)
- aircraft type (TYPE)
- aircraft code number (CODE)
- cabin configuration (CONFIG)
- version of the crew (CREW VERSION)
- date (DATE)

Data that do not have to be entered using the keyboard but are loaded from the database are:
- Dry Operating Index
- Take-off Fuel
- Trip Fuel

The possible form of display is given in Figure 15,

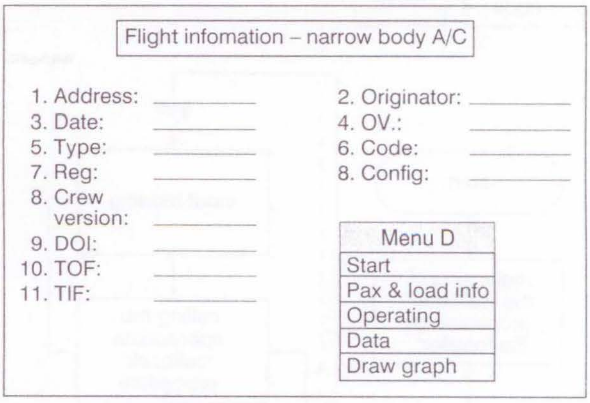

Figure 15

The suggested flowchart is the basis for developing the concrete application so that a possibility is left to select the operational system, graphic interface and the programming language itself.

SAŽETAK

MOGUĆNOST PRIPREME PODATAKA U ZRAKOPLOVNOJ LUCI ZA PRIHVAT I OTPREMU ZRAKOPLOVA U SVEZI S OCJENOM URAVNOTEŽENOSTI ZRAKOPLOVA NA RAČUNALU

U ovom se radu obrađuju mogućnosti pripreme podataka za izradu sveobuhvatnog računalnog autonomnog programa pri prihvatu i otpremi zrakoplova u zračnoj luci povezanog sa zrakoplovnom lukom iz koje dolazi zrakoplov, a istovremeno i sa zračnom lukom u koju odlazi zrakoplov ako je u prolazu.

Daje se pregled gotovo svih utjecajnih čimbenika i način za njihovo razvrstavanje u obliku uporabljivom na računalu koje će primati sve dolazne podatke i informacije o zrakoplovu u dolasku , kako bi se omogućilo što brže opskrbljivanje, opremanje i uravnotežavanje zrakoplova u odlasku.

LITERATURE

[1] International Air Transport Association: *Airport Handling Manual*, 16th Edition Effective, April 1, 1996

[2] **E. L. Houghton**, **A. E. Blook**, *Aerodynamics for Engineering Students*, Edward Arnold (Publishers) LTD, London I.S.B.N.), 1970.

[3] **Dan Heller**: *XView Programming Manual*, O Really & Associates