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TRANSPORT AIRCRAFT LOADING AND BALANCING SYSTEM : USING A CLIPS EXPERT SYSTEM FOR MILITARY AIRCRAFT LOAD PLANNING.

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ABSTRACT

The requirement for improving aircraft utilization and responsiveness in airlift operations has been recognized for quite some time by the Canadian Forces. To date, the utilization of scarce airlift resources has been planned mainly through the employment of manpower-intensive manual methods in combination with the expertise of highly qualified personnel. In this paper, we address the problem of facilitating the load planning process for military aircraft cargo planes through the development of a computer-based system. We introduce TALBAS (Transport Aircraft Loading and BAlancing System), a knowledge-based system designed to assist personnel involved in preparing valid load plans for the C130 Hercules aircraft. The main features of this system which are accessible through a convivial graphical user interface, consists of the automatic generation of valid cargo arrangements given a list of items to be transported, the user-definition of load plans and the automatic validation of such load plans.

INTRODUCTION

The aircraft load planning activitiy represents the complex task of finding the best possible cargo arrangement within the aircraft cargo bay, given a list of various items to be transported. In such an arrangement, efficient use of the aircraft space and payload has to be made while giving due consideration to various constraints such as the aircraft centre of gravity and other safety and mission related requirements. The diversity of the equipment to be transported and the variety of situations which may be encountered dictate that highly trained and experienced personnel be employed to achieve valid load plans. Additionally, successful support of military operations requires responsiveness in modifying conceived load plans (sometimes referred to as "chalks") to satisfy last-minute requirements.

The development of a decision support system to assist load planning personnel in their task appears to be a natural approach when addressing the simultaneous satisfaction of the numerous domain constraints. The chief idea behind TALBAS consists of encoding the knowledge of domain experts as a set of production rules. The first section of this paper is devoted to a description of the fundamental characteristics of the load planning problem. A review of major contributions and research work in the field of computer-assisted load planning is then presented. The next section provides a detailed description of the TALBAS architecture and an overview of the modelled reasoning approach used to achieve valid load plans. Finally, a list of possible extensions to the current system is given.

PROBLEM STATEMENT

The problem of interest may be briefly stated as summarized by Bayer and Stackwick [1]:

> " there are various types of aircraft which may be used, each with different capabilities and restrictions and different modes in which it may be loaded, and finally, there is a large variety of equipment to be transported."

Additionally, the load's center-of-balance must fall within a pre-defined Center of Gravity (CG) envelope for all loading methods, otherwise imbalance can render the airplane dynamically unstable in extreme cases.

First addressing the issue of diversity of equipment to be transported, we note that each aircraft can be loaded with cargo including any or all of the following items: wheeled vehicles, palletized cargo, tracked vehicles, helicopters, miscellaneous equipment and personnel. Each type of cargo item requires different considerations. The wide variety of cargo items to be loaded poses a significant difficulty in that a feasible load configuration has to be selected from a very large number of possible cargo arrangements, given a number of pre-defined areas within the aircraft cargo bay which may each impose different restrictions on the type of item which may be loaded depending on weight limitations and other constraints.

Secondly, the load arrangements are dependent upon the following delivery methods : strategic air/land, airdrop, low-altitude parachute extraction system (LAPES) and tactical air/land.
For strategic air/land missions, the emphasis is on maximum use of aircraft space and few tactical considerations are involved. In a tactical air/land mission however, speed and ease with which cargo can be on-loaded and off-loaded takes precedence.

Airdrop operations consist of off-loading equipment and personnel by parachute. LAPES is executed when the aircraft is flown very close to the ground over a flat, clear area. In this case, an extraction parachute is deployed from the rear of the aircraft, after which the aircraft reascends. The equipment, mounted on a special platform, is pulled from the aircraft by the drag on a parachute and skids to a halt. Airdrop and LAPES missions must maintain aircraft balance while dropping cargo and must also provide space between items for parachute cables.

A third issue concerns the characteristics and limitations pertaining to the type of aircraft being loaded. The load capacity of an aircraft depends on its maximum design gross weight (i.e., weight when rounded or upon take-off), its maximum landing gross weight and maximum zero fuel weight (i.e., weight of aircraft and its load when fuel tanks are empty). The maximum design gross weight includes the fuel load to be carried which is determined, at the outset, on the basis of the distance to be flown and other operational requirements. The established quantity of aircraft fuel in turn influences the allowable load which corresponds to the maximum cargo/personnel weight the aircraft can carry.

Finally, constraints pertaining to loading, unloading and in-flight limitations have to be checked when an item is loaded into the aircraft cargo bay. To model a realistic situation, safety and mission related restrictions and parameters such as transport of dangerous goods and cargo/personnel movement priorities, are also taken into account in the set of constraints.

A mathematical formulation of the aircraft loading problem may be obtained through the application of Operations Research techniques. The underlying closely related bin-packing problem (Friesen and Langston [2]) is known to be NP-hard in the strong sense, suggesting it is unlikely that a polynomial solution exists (Garey and Johnson [3]). However, if the requirement of finding the best solution is relaxed to finding a good solution, then heuristic techniques can be applied successfully (Pearl [4]). For a number of reasons to be presented later in this paper, we propose to adopt a heuristic approach based on the knowledge of domain experts. In the following section, we undertake a review of two successful endeavors aimed at facilitating aircraft load planning, that is AALPS and CALM.

The Automated Aircraft Load Planning System (AALPS)

AALPS was developed for the US Forces in the early 1980s, using the Sun workstation as the platform. This load planning tool is a knowledge-based system built using the expertise of highly trained loadmasters.

The underlying system architecture is designed to serve three basic functions: the automatic generation of valid loads, validation of user-defined load plans and user-modification of existing load plans. To perform these tasks, AALPS incorporates four components:

1) a graphical user interface which maintains a graphical image of the aircraft and equipment as cargo items are being loaded;
2) an equipment and aircraft databases which contain both dimensional information and special characteristics such as those required to compute the aircraft CG;
3) the loading module which contains the procedural knowledge used to build feasible aircraft loads; and
4) a database which allows the user to indicate his preference from a set of available loading strategies.

Despite its seemingly powerful features, AALPS would probably necessitate some improvements at significant costs to meet the requirements of the Canadian Forces.

Another initiative in the area of computer-assisted load planning led to the implementation of the Computer Aided Load Manifest (CALM), which was initiated by the US Air Force Logistics Management Centre in 1981.

The Computer Aided Load Manifest (CALM)

The project to develop CALM, formerly called DMES (Deployment Mobility Execution System), was launched at approximately the same time as AALPS but the established objectives were slightly different. In contrast with AALPS, CALM was to be a deployable computer-based load planning system. Consequently, the selected hardware was to be easily transportable and sufficiently resistant for operation in the field.

CALM uses a modified cutting stock heuristic to generate "first-cut" cargo loads, which the planner can alter through interactive graphics.

This system incorporates fewer functional capabilities than AALPS and runs on a PC compatible platform, thus resulting in significantly lower development costs. A major reproach, however, is that this system does not appear to take explicitly into account important load planning data such as the weight of the aircraft fuel being carried, hence leading to incomplete results in some cases. Additionally, the graphical interface would require some improvement to be considered sufficiently user-friendly. In spite of these deficiencies, CALM remains a very useful tool to aid in the load planning process.

In view of the successful research work accomplished in the area of automated aircraft load planning based on the emulation of expert behavior in this field, we have decided to concentrate our efforts on the development of an expert system. The intent in doing so, is to combine the most valuable features present in the existing systems, namely AALPS and CALM, and to adapt them to produce a tool tailored to the Canadian military environment. Our objective is to develop a system with the following features:

1) be deployable to and operable at remote sites;
2) be easy to use and provide a convivial user interface;
3) be capable of handling aircraft load planning problems involving a wide variety of items and several aircraft types used by the Canadian Forces;
4) deal with different types of mission, including the ones with more than one destination;
5) automatically generate valid load plans in a reasonable time;
6) allow the user to alter plans automatically generated by the system;
7) allow users to define their own load plans and issue warnings whenever constraints are violated.

The next section will describe the functional architecture and design of TALBAS which enable the integration of the above described desired features.

THE SYSTEM ARCHITECTURE

The functional architecture depicted at Figure 1 serves the same three basic functions as in AALPS: automatic generation of cargo arrangements, user-definition of load plans and automatic validation of existing load plans. TALBAS consists of an interactive user interface, a loading module, a mission and an aircraft database, and necessary communication links for access to some databases available within the Canadian Forces. The following provides a description of the various databases required to build a feasible cargo load:

1) the aircraft database contains detailed aircraft characteristics including dimensional information and a description of the constraint regions for the C130 Hercules aircraft;
2) the mission database contains detailed mission features mainly in the form of applicable loading strategies;

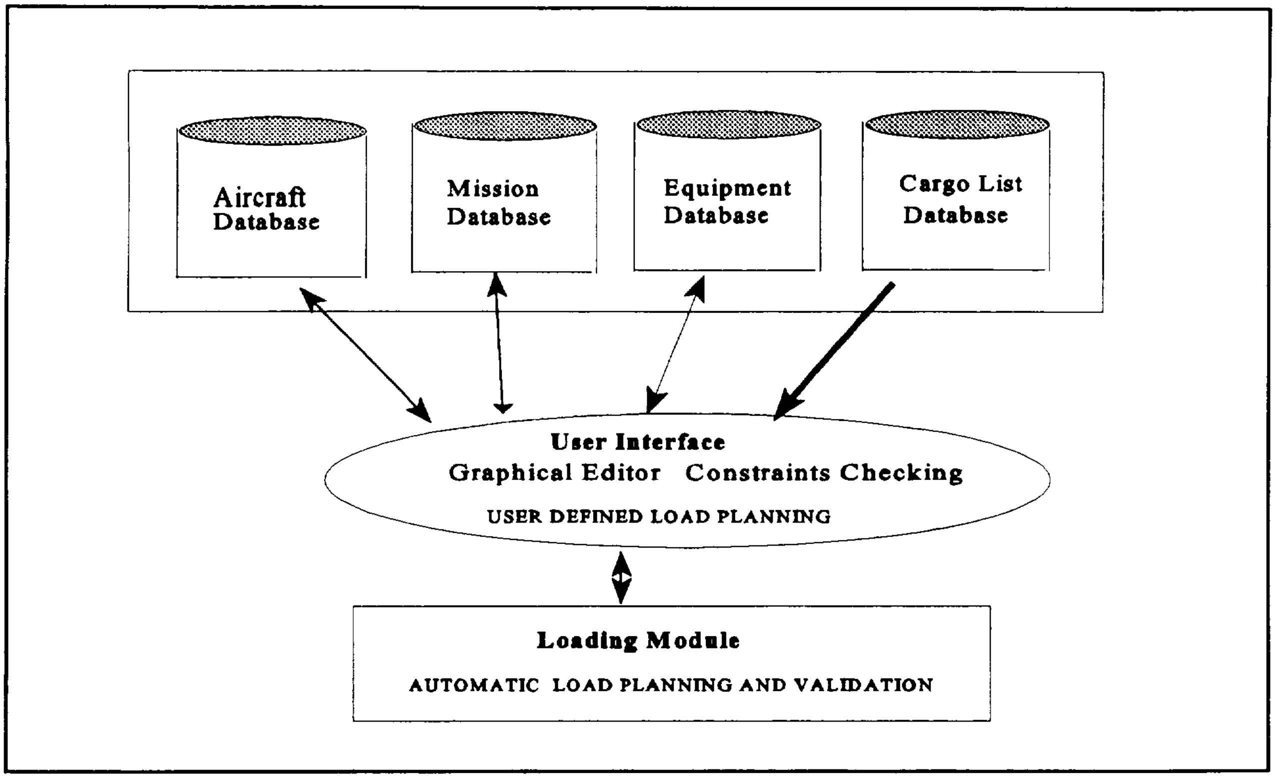

Figure 1 : TALBAS Functional Architecture

3) the equipment and cargo list databases together provide a detailed listing of all cargo items and personnel to be deployed for a mission, including all necessary information about each particular object such as the weight and dimensional characteristics, and the order in which the items are to be transported To minimize the requirement for user input, a set of default values are provided for the majority of the objects' characteristics and these may be changed at the user's request as the situation dictates.

The user interface module performs two main tasks: the graphical display and the constraints checking. The aircraft floor and the items being loaded are graphically represented on the screen. Objects representing loaded cargo items and the various areas of the aircraft cargo floor are drawn on the basis of information available in the different databases described above. All onscreen cargo items are treated as active objects; they can be dragged and moved within the aircraft cargo bay after being selected with a mouse.

The constraints checker ensures that any violation of the center of gravity limits or of other in-flight restrictions is reported through the display of warning message dialog boxes. All the critical load planning data, such as the aircraft CG upon take-off, are computed every time an item is placed or moved within the aircraft cargo area.

The loading module basically consists of an expert system which automatically generates valid load plans. The load planning process will be reviewed in details in the next section.

TALBAS has been developed through the implementation of an incremental prototyping methodology whereby the end user is continuously involved in the refining process of the current prototype. The availability of an ever-improved GUI and loading module, allows for a fail-safe capture of user requirements. The PC platform has been selected for development purposes in order to produce, in a cost effective fashion, a deployable tool operable at remote sites as a stand-alone system. TALBAS has been designed with an object oriented approach to favor reusability.

The user interface has been implemented using Microsoft Windows and C++. The expert system portion of TALBAS is an enhanced application of the expert system shell CLIPS. This module has been created as a Dynamic-Link Library (DLL). A DLL is a set of functions that are linked with the main application at run time which is, in our case, the user interface. When faced with the problem of having CLIPS communicate with the graphical user interface, three alternatives were contemplated: embedding of CLIPS-based loading module into the main program; implementation of the CLIPS-based loading module as a DLL: or use of the Dynamic Data Exchange (DDE) concept.

DDE is most appropriate for data exchanges that do not require ongoing user interaction. However, the requirement for the devised expert system to constantly monitor any changes made by the user when modifying load plans onscreen has made the approach an unacceptable one. Embedding the CLIPS-based loading module within the main application required that both the user interface and the loading module fit within 64K of static data. This is not possible since the CLIPS-based application (version 6.0) uses all this amount of memory space. On the other hand, implementing the CLIPS-based application as a DLL allows the former and the user interface to be considered separately such that each of the two application codes can fit within the limit of 64K of static data.

The Loading Module

A heuristic approach has been selected as a solution to address the load planning problem. The loading methodologies applied by loadmasters and load planners have been encoded as a set of production rules. This choice was first motivated by the fact that rules of thumb are often the only means available to the experts when seeking a good first try---one requiring the fewest alterations---to achieve a valid load. As an example, load planning experts generally agree to follow a "60--40'' rule of thumb, namely 60% of the load weight has to be located at the front of the aircraft and 40% at the rear. The second reason for the choice of a knowledge-based system is that the expert knowledge represented in the form of production rules can be easily maintained and updated to incorporate new assets as they are acquired by the Canadian Forces or to adapt to new situations.

Among the three basic objectives, namely the automatic generation of valid load plans, the automatic validation of user-defined load plans and the user-definition of load plans, the first two are achieved using the expert system in TALBAS. The third objective is achieved through the implementation of a graphical user interface allowing the user to manipulate objects onscreen. The expert system is made of two distinct modules as can be seen from Figure 2. The Loading knowledge-base contains all the information related to aircraft loading procedures while the rules contained in the Validation knowledge-base allow the system to recover from situations characterized by a non-balanced aircraft or violated constraints.

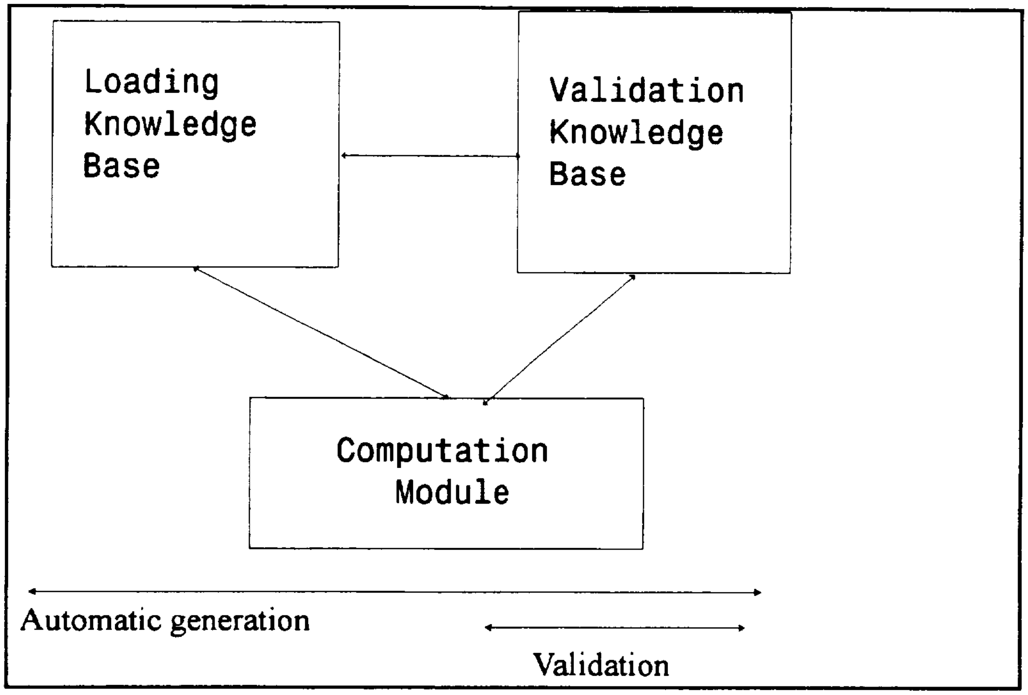

Figure 2 : TALBAS Expert System

The Loading knowledge-base contains all rules which are essential to initially identify one possible load configuration. As in AALPS, an initial cargo state contained in a database of facts is iteratively transformed by our system into an acceptable cargo arrangement by applying a sequence of operators representing the loadmaster's knowledge. In generating a load configuration, pre-defined areas of the aircraft floor are assigned to each category of items or passengers to be transported. For instance, when both cargo and passengers have to be loaded, passengers are usually assigned to the front of the aircraft. Next, a selection of the appropriate item in each category (e.g. vehicles) is made, based on weight, width and length considerations. Since the aircraft balance is a primary concern, a preliminary selection among all cargo items is accomplished on the basis of weight followed by consideration of dimensional information depending on the type of item selected. The integrated computation module will subsequently compute the achieved CG and verify that numerical constraints have not been violated.

At this step, the coded heuristics contained in the loading knowledge-base are likely to have produced an acceptable "first-cut" load plan. However, the system will try to find a cargo arrangement characterized by an optimal CG value while ensuring that all constraints are satisfied. If the initial load is not acceptable, the system will make use of rules stored in the validation knowledge-base to first slide the loaded items, if there is sufficient aircraft space remaining to do so, or attempt to rearrange these items if sliding operations are not feasible. TALBAS will stop when it has identified either an optimal load plan or an acceptable one. In such cases where no possible solutions may be found for the list of given items to be loaded and no more permutations can be made, the system issues a warning message indicating that no valid load plans can be found with that combination of items.

A second role played by the expert system module concerns the validation of user-defined load plans. In this case, it operates in the same fashion as described above when automatically generating valid load plans with the difference that the initial load plan is produced by the user himself.

CONCLUSION AND FUTURE WORK

In this paper, we have presented a knowledge-based alternative to facilitate load planning of military aircraft. We have successfully incorporated most of the valuable features present in the existing systems, AALPS and CALM, and adapted them to produce a tool tailored to meet the specific requirements of the Canadian military environment. The major concerns which have been addressed were the deployability and conviviality of the designed system. The CLIPS-based expert system module automatically generates valid load configurations and validates user-defined/modified load plans. The developed graphical user interface allows for the easy alteration of existing plans.

Efforts in the design of the developed system have been primarily focused on the loading of the C130 Hercules aircraft, since it is currently the principal airlift resource used by the Canadian Forces for the transport of cargo and personnel. The system may however, be easily adapted to accommodate other existing or future types of Canadian Forces transport aircraft. Expansion of TALBAS to permit the loading of several aircraft, while giving due consideration to the movement priority level assigned to each item to be airlifted, is currently under development.

REFERENCES

[1] Bayer, W.K., and Stackwick, D.E., "Airload Planning Made Easy", ARMY LOGISTICIAN, May-June, 1984, pp. 34-37.
[2] Friesen, D.K., and Langston, M.A., "Bin Packing: On Optimizing the Number of Pieces Packed", BIT, 1987, pp. 148-156.
[3] Garey, M.R., and Johnson, D.S., COMPUTERS AND INTRACTABILITY: A GUIDE TO THE THEORY OF NP-COMPLETENESS, W.H. Freeman, San Francisco, California, 1979.
[4] Pearl, J., HEURISTICS: INTELLIGENT SEARCH STRATEGIES FOR COMPUTER PROBLEM SOLVING, Addison-Wesley, Reading, Massachusets, 1984.
[5] Anderson, D., and Ortiz, C., "AALPS: A Knowledge-Based System for Aircraft Loading", IEEE, Winter 1987, pp. 71-79.
[6] Cochard, D.D., and Yost, K.A., "Improving Utilization of Air Force Cargo Aircraft", INTERFACES, January-February, 1985, pp. 53-68.
[7] Ignizio, J.P., INTRODUCTION TO EXPERT SYSTEM: THE DEVELOPMENT AND IMPLEMENTATION OF RULE-BASED EXPERT SYSTEMS, McGraw-Hill, Houston, Texas, 1991.
[8] Ng, K.Y.K., "A Multicriteria Optimization Approach to Aircraft Loading", OPERATIONS RESEARCH, November-December, 1992, pp. 1200-1205.