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DEVELOPMENT AND VISUALIZATION OF THE COMPUTER LOADING PLANNING MODEL FOR THE CARGO AIRCRAFT

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Loading an aircraft is an extremely complex process with many variable aspects that determine the planning of each flight separately. The article is devoted to the development of an algorithm and a computer model for planning the loading of a cargo ramp aircraft in a multi-lag route. The essence of the algorithm consists in a predetermined arrangement of cargo containers relative to the cargo compartment, taking into account the general limitations of the aircraft and the priority of the cargo, which directly affects the planning of loading in a multi-lag route. The use of a visualized computer model created on the basis of the algorithm can reduce the average time of loading operations for a number of direct flights by almost 7 %, and on multi-lag flights by 12 %.

Implementation of the model in the activities of an air carrier avoids a situation where certain criteria and restrictions entail sorting «manually» by all indicators, which is very time-consuming in the context of the urgency of servicing the aircraft at the airport.

The visualized load planning computer model enables flight planning personnel to make faster decisions and predict additional load on other sections of the route.

The successful application of the model to the airline's operations contributes to the efficiency and safety of ground handling services. This contributes to the intensification of the use of the aircraft fleet by increasing the speed of commercial cargo handling.

In the future, the computer model can serve as the basis for a rule-based expert system in order to prevent containers from being overloaded at intermediate sections of the route

Keywords: freight container (ULD), optimal load, load planning algorithm, computer model, expert system

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1. Introduction

Success in the air freight sector is closely tied to the ability to consolidate freight shipments. Optimizing loading operations plays a key role in the sustainability of a cargo airline's operations. The process participants involved in the loading process have different goals. The aim of the sales department is to maximize profits and the number of shipments, the handling (commercial service) aims to minimize its efforts, while the production department tries to minimize fuel consumption and the use of freight containers.

The aircraft loading process is a complex process that includes four separate handling processes: cargo separation, cargo removal, movement and distribution of cargo. These processes have certain grouping rules:

1. Exclusion of cargo. If the total weight of a group of cargo exceeds the maximum permitted commercial load or the total volume does not correspond to the boundaries of the container, the cargo should be excluded from the list of cargo for a specific flight.

2. Distribution of cargo. To streamline the commercial handling of cargo (handling agents), it is usually packed in pallets or containers, called ULD.

3. Moving of cargo. While the distribution of the cargo is taking place, the next destination to the longest along the route must be moved through the cargo group with a closer destination in order to avoid blocking.

4. Division of cargo. There are two types of cargo division. Some groups of cargo are divided to carry such cargo in as large a quantity as possible. The second type occurs when large groups of objects are distributed in containers of certain sizes, and are also divided into several groups [1, 2].

Commercial ground handling of aircraft is one of the main components of ensuring the safety and regularity of international air traffic. Handling services cover all types of services provided by aircraft, as well as the cargo that is transported.

The search for new methods of optimal loading will help to reduce the number of events and incidents with civil aircraft, as well as increase the efficiency of their service and the competitiveness of international air cargo carriers.

2. Literature review and problem statement

The process of organizing air cargo transportation takes place between the shipper, the forwarder and the «feeder» (from the English «the one who brings up») mode of transport. Subsequently, the air carrier and the consignee enter this process. Fig. 1 shows a diagram of the technological process of interaction of air cargo transportation [1].

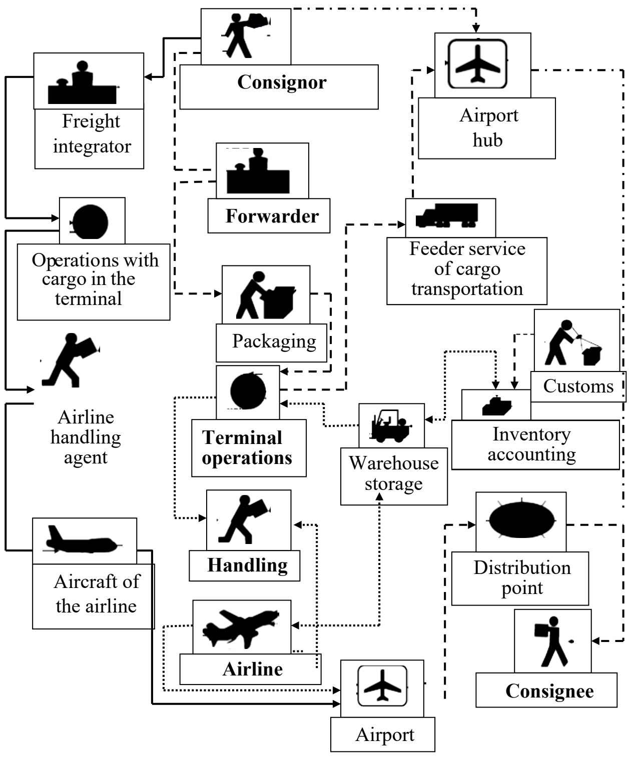

Fig. 1. Technological process of interaction of subjects of air cargo transportation [1]

The loading process itself is a key link in this process flow diagram, therefore, the further algorithm of actions of other participants in the loading process depends on its optimization.

The analysis of economic indicators indicates an increase in the volume of air cargo transportation, on average by 3 % per year, at least until 2025, and it is likely that this growth will continue until 2030 [3].

Analyzing the competitive environment of air carriers, it becomes clear that the majority are looking for tools to ensure more efficient commercial loading in order to increase their profitability, fuel efficiency and optimize other components of operating costs.

Optimization models and solutions are investigated that are of scientific and practical importance. They include such aspects as the load on the support, as well as its distribution of the load as in [4, 5, 7]. However, in the work [4], the emphasis is placed on two-dimensional packaging, which excludes the possibility of perfect visualization of the loading process. The aim of the work [5] is to maximize the value of the cargo, which is not the main goal of this work, since it considers homogeneous cargo and the speed of its servicing on the apron. The work [7] highlights scientific attempts in organizing optimal loading solutions, but is limited to the «rectangle of the center of mass».

In a work [8], for efficient loading in accordance with constraints, it was decided to reduce the unproductive time only by reducing the packaging time. In [6, 9], the results of the study are presented, containing the planning and organization of loading by stacking, which excludes the possibility of planning a multi-lag voyage. In [10], a hybrid genetic algorithm is presented in the framework of the heuristic approach to loading an aircraft; however, it complicates the deduction of the exact number of containers for loading. There are also «taboo search» optimization models, that is, search with limited capabilities, described in [11] and the rule-based optimization in [12]. But without the computational part, such models can give only an approximate result for planning.

In addition, the optimization problem is still NP complex (not polynomial, that is, with an indefinite time), and the options for solutions grow exponentially. It is on the basis of this approach that a mathematical algorithm of mixed integer programming was created in [13], which, according to the authors' hypothesis, guarantees finding an optimal solution for the problem of three-dimensional packing. However, practical studies prove that the model is not efficient enough under conditions of a route consisting of several points and, despite the processing of a large amount of variable data. The work [13] solves the optimization problem with 32 variables, but calculating a larger number of options is more complicated and takes a lot of time.

Optimization of aircraft load planning is extremely important, since it directly affects the speed of operations with commercial services.

The analysis of previous scientific approaches to optimal loading methods allows to assert that it is expedient to develop a computer model for loading planning, to combine mathematical and computer algorithms in its database, and will also contain a heuristic component, which will allow changing the indicators and visualizing the three-dimensional model in real time.

3. The aim and objectives of research

The aim of research is to develop and visualize a computer model for planning the loading of a cargo aircraft. The speed of decision making when planning loading in an uncertain number of containers and route helps to reduce loading times and reduce aircraft operating costs.

To achieve the aim, the following objectives were set:

– to develop an updated decision-making algorithm for planning aircraft loading, taking into account the aircraft restrictions and the criterion of cargo priority;

– to implement and visualize a computer model of load planning;

– to experimentally check the effectiveness of the created model.

4. Materials and methods of research

To analyze the interaction of loading processes throughout the entire technological process of loading, the process and system approaches were used. In order to objectively comprehensively study the factors and trends in the development of international air cargo transportation, statistical methods were used. To create a computer model for planning the aircraft load, the methods of computer modeling and heuristic methods (based on the data of expert evaluation) were used. The adequacy of the investigated model was checked using the method of experimental research and the statistical criteria of Student, Fisher and Wilcoxon.

All algorithms, the pseudocodes of which are presented in the article, were formalized into Python program code.

The load planning computer model was created using a computer with an Intel (R) Core (TM) i5 – 3210 M CPU@2.50 HGz processor and a 64-bit Windows 2007 operating system. The software implementation was completed in the 3D modeling program Blender version 2.83 Beta in the Microsoft Visual environment. Studio that is compatible with the Python programming language.

5. Research results of the influence of the computer model of loading planning on the time indicators of cargo servicing

5. 1. Development of a decision-making algorithm for planning aircraft loading

The Blender simulation program included graphs of the dependence of the location of the resulting center of gravity and aircraft loading patterns, including: AN-26, AN-124, IL-76 and AN-22 and Boeing 737-800 Freighter. The IL-76 aircraft was proposed as an example for modeling loading planning. The essence of the algorithm is that the cargo compartment in a particular case is divided into 15 sections (groups) Fig. 2. The section of the cargo compartment of any cargo aircraft corresponds to its location and is divided into a certain number of fuselage partitions in accordance with its length parameters [5]. If it is necessary to investigate another cargo plane with a ramp, then according to its own centering plan (already loaded into the base), the parameters of the length, width and height of the cargo compartment are changed.

The dependence of the center of gravity on the total mass is a prerequisite, which indicates the safety of aircraft loading. Such a plan for each aircraft is included in the flight operations manual of each type. Type is a specific type of aircraft. After all, the configuration and parameters of the same aircraft may differ. According to this indicator, the conditions for the necessary decision-making algorithm when planning the load are further built on the graph. The following algorithm of actions during planning follows precisely from the parameters indicated in Fig. 2.

Example case 1:

ULD container follows from point A to C (through point B):

1. Consequently, the ULD container ci belongs to the segment 1 (L1).

Container dimensions ($L\times W\times H$), $d_i\le$dimensions of the cargo compartment, D.

If the requirements are met, then:

2. Check, the final weight of the container, $w_i \le w_{Sn}$ weight restrictions for *i*, *j*, *k* groups of sections.

Note:

Three groups of cargo sections are given – *i, j, k*.

k is a group of sections for the cargo to be unloaded at the intermediate section of the AB route. This group includes sections No. 11–15. (Fig. 2).

j is a group of sections for the cargo to be unloaded at the intermediate segment of the B-C route. This group includes sections No. 6–10.

i is a group of sections for the cargo following from point A to the final point of route C. This group includes sections No. 1 5.

3. In the first section, the i-group should be loaded (all cargo follows to the final point C).

4. If the section has free space and the actual weight $w_i < w_{Si}$ is maximum calculated for this section (Fig. 2), then:

5. Loading a section with the next containers in the list correspond to the same destination.

6. If there is no free space or, $w_i = W_{\max}$ (the actual commercial load of the section is equal to the maximum), go to the next sections $S_{i+1.}$

7. Repeat step 6 until $w_{Si} \le w_{iload}$ the maximum payload of a certain group of sections is less than or equal to the final weight of loaded containers according to their defined sections.

8. Repeat steps 1-6 for other groups of sections (*i*, *j*, or *k*).

9. Check all load indicators.

10. End of the algorithm.

There are similar algorithms that have only one variable – the route to follow. At this stage, decision-making options (replaceable) were selected in accordance with the selected containers with their dimensions and other parameters that characterize, including general physical limitations.

The previous textual algorithm after formalization in Python is shown in Fig. 3.and Fig. 4.

In Fig. 4, codes of containers (AMA, CTC, KMA and PLA) and their weight restrictions are indicated. If the actual indicators do not correspond to the weight restrictions entered into the algorithm the day before, the container will not be loaded to a specific aircraft, and the system provides the next one for checking compliance.

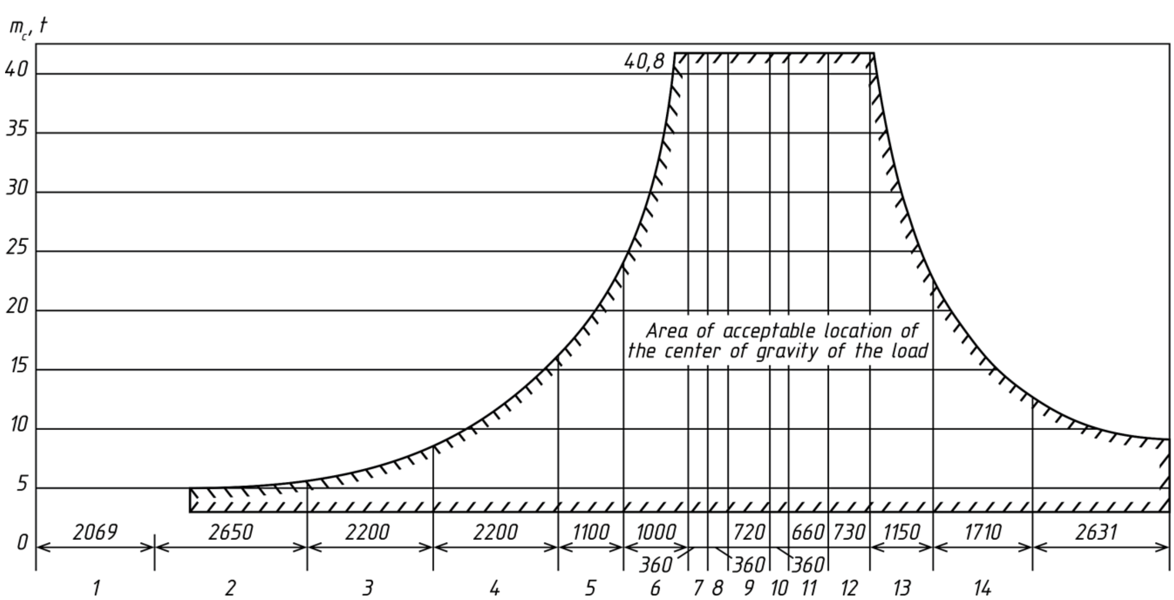

Fig. 2. Graph of dependence of the location of the resulting center of gravity of the IL-76 aircraft on its total mass [14]

The algorithm redistributes variants of mass distribution and arrangement of individual containers in different sections of one group of three possible. The available free spaces belonging to certain sections of the cargo compartment and corresponding to its weight limits continue the algorithm until the next suitable cargo fills the section (subject to centering and loading).

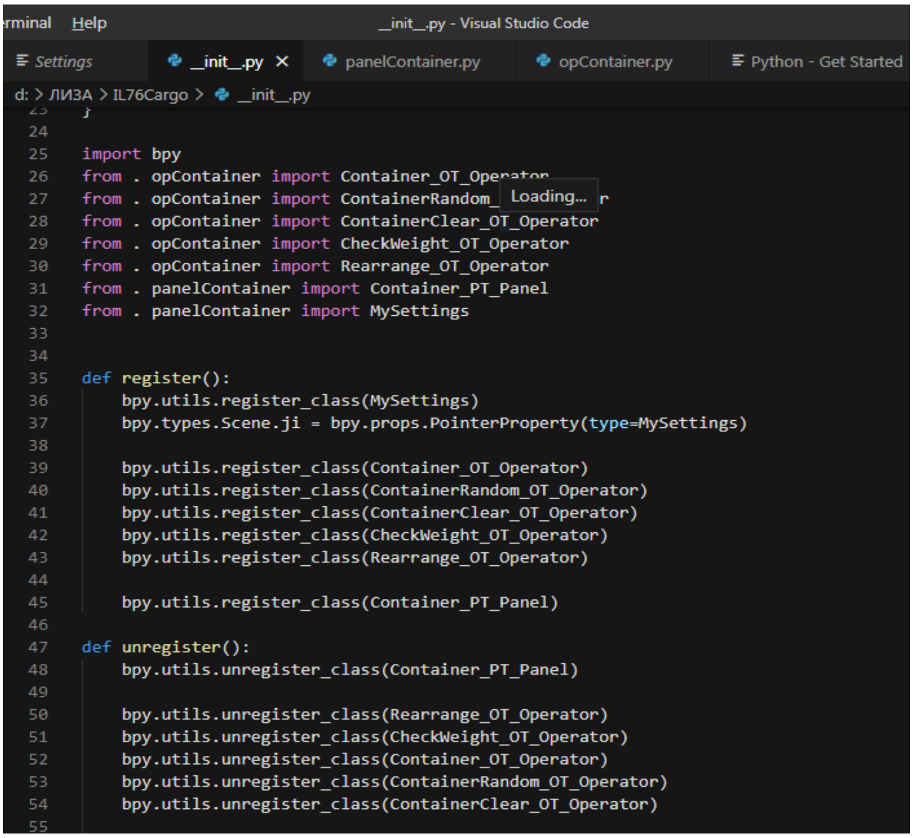

Fig. 3. Python formalized load planning algorithm, part: initialization of classes

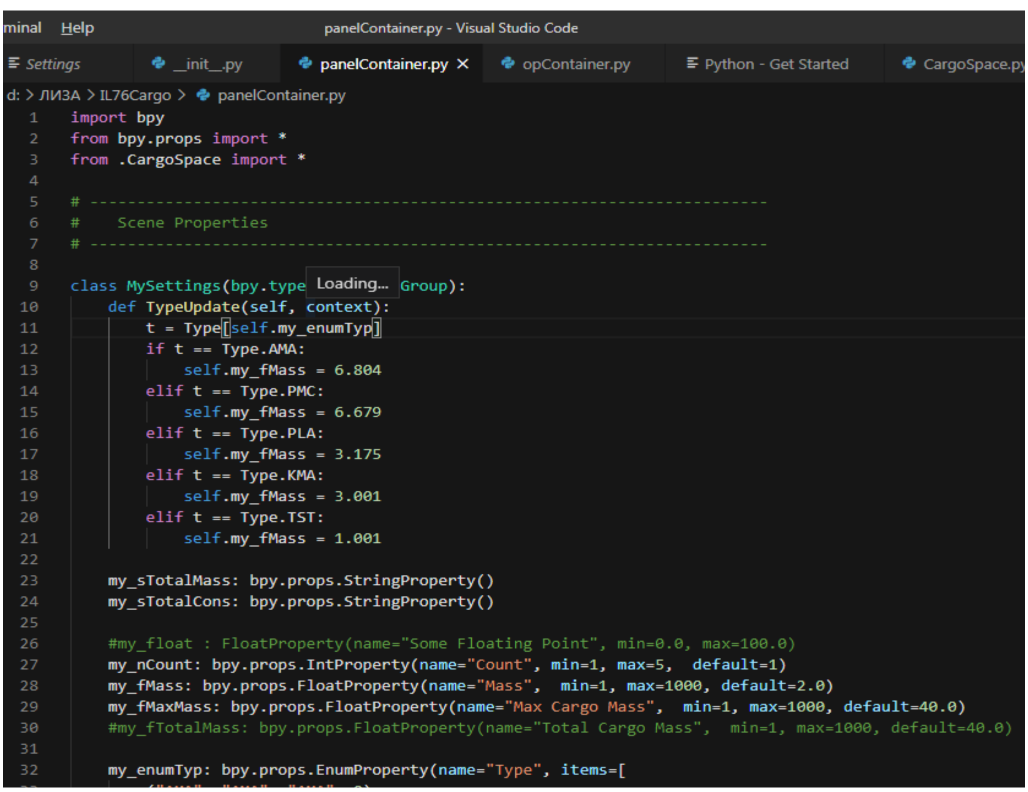

Fig. 4. Python coded load planning algorithm, part: introducing parameters

5. 2. Implementation of a computer model for planning the loading of a cargo aircraft

The load planning model is implemented as follows:

1. The program database contains information about a certain number of containers for planning loading within a multi-lag route. This information is provided from documents prepared by an employee engaged in flight planning (Flight Dispatch, Ground Dispatch, etc.), or by several flight planning employees of the airline [15].

2. Typical types of containers used by the airline are entered into the program in advance. These are Type A (KMA) containers for transporting animals, and general purpose ULDs PMC, PLA and AMA.

3. The program, using the introduced general restrictions of the aircraft (length, width and height of the compartment, maximum commercial load), restrictions on centering and restrictions on loading for a specific section, selects the «Add container» container. The container places it first in relation to its priority criterion (belonging to a certain route), as shown in Fig. 5 using the «By path» command.

5. The program also contains data from the graph of the dependence of the location of the resulting center of mass of aircraft cargo (in this case, the IL-76 aircraft) on their total mass (Fig. 2). Consequently, the distribution of the weight of the containers is strictly according to the schedule, so the centering will not be obtained outside the standard indicators. Therefore, in Fig. 6, container is already located not only by the priority criterion, but also in the center using the «by balance» command.

6. By successively adding certain types of containers corresponding to the given priority of the route, the type and location of all containers loaded by the program relative to the plane of the cargo compartment changes (Fig. 7, 8).

7. When adding and placing containers with two criteria at the same time, it may happen that the weight of the container that is loaded last is within the normal range. However, in terms of its dimensions, it exceeds the indicators of the overall dimensions of the cargo compartment, as shown in Fig. 9. In this case, it is possible to exclude it from the list, and select another container with the help of the «Add container» command, which will be suitable also by its size, and not protruding beyond the ramp.

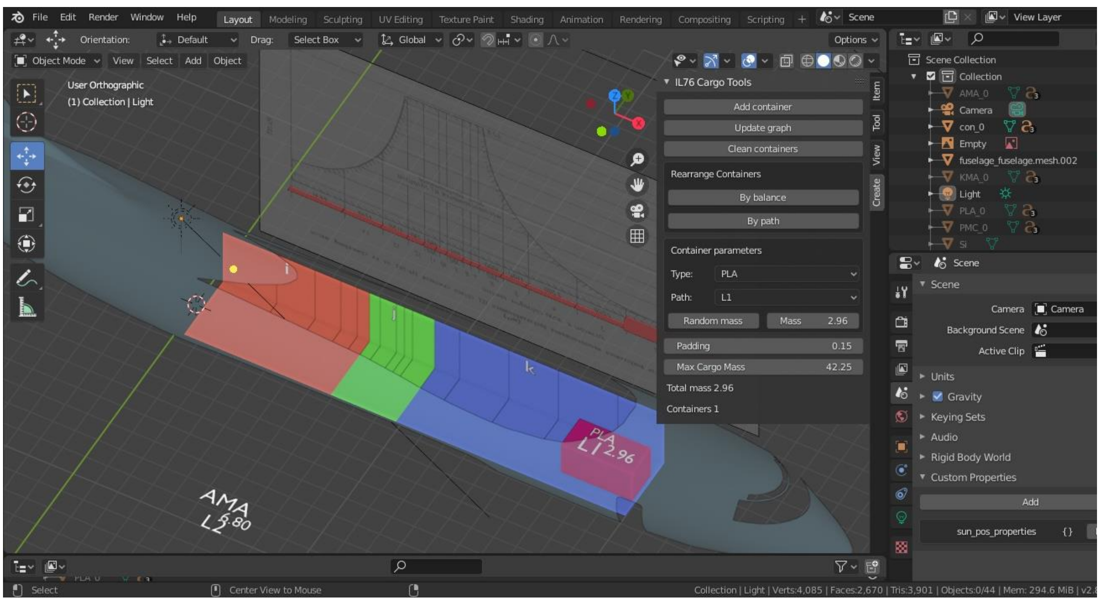

Fig. 5. Visualization of the model: Choosing the location of the container according to the priority of its unloading

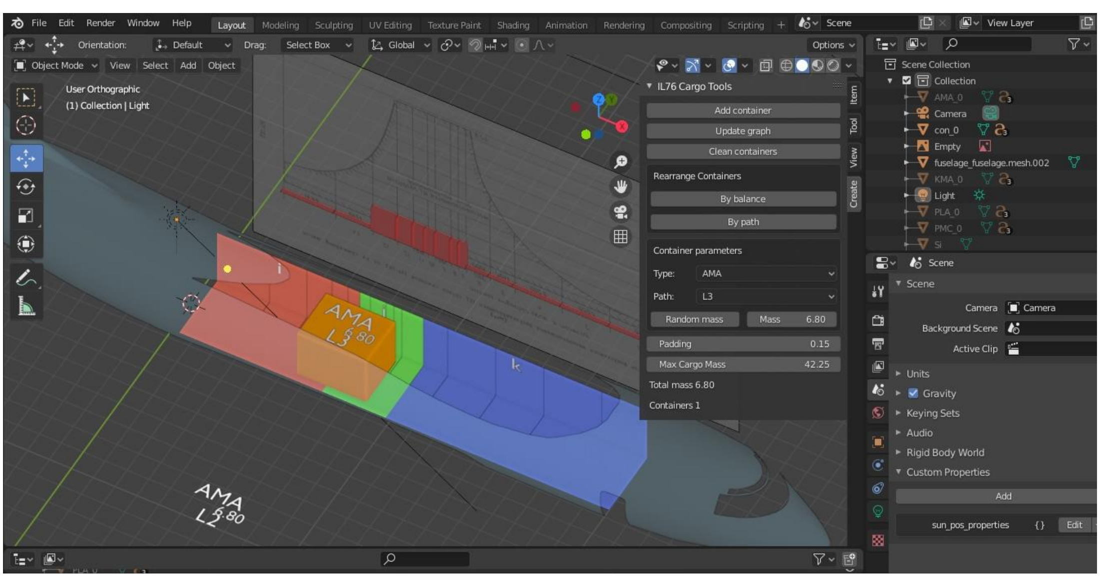

Fig. 6. Visualization of the model: Container located according to the requirements of the alignment and loading schemes

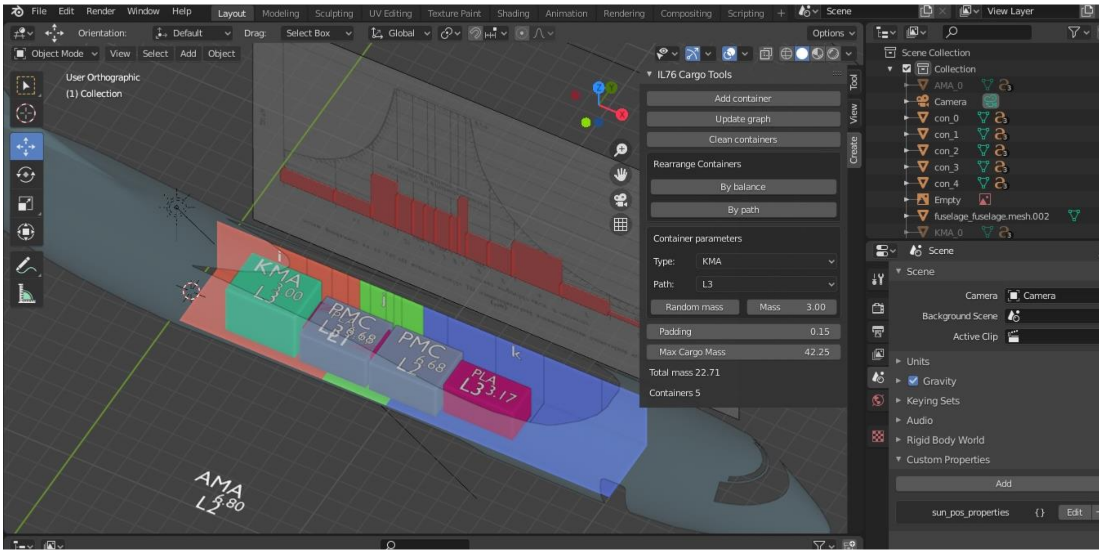

Fig. 7. Visualization of the model: Loading several containers of different characteristics according to the requirements of the alignment and loading schemes

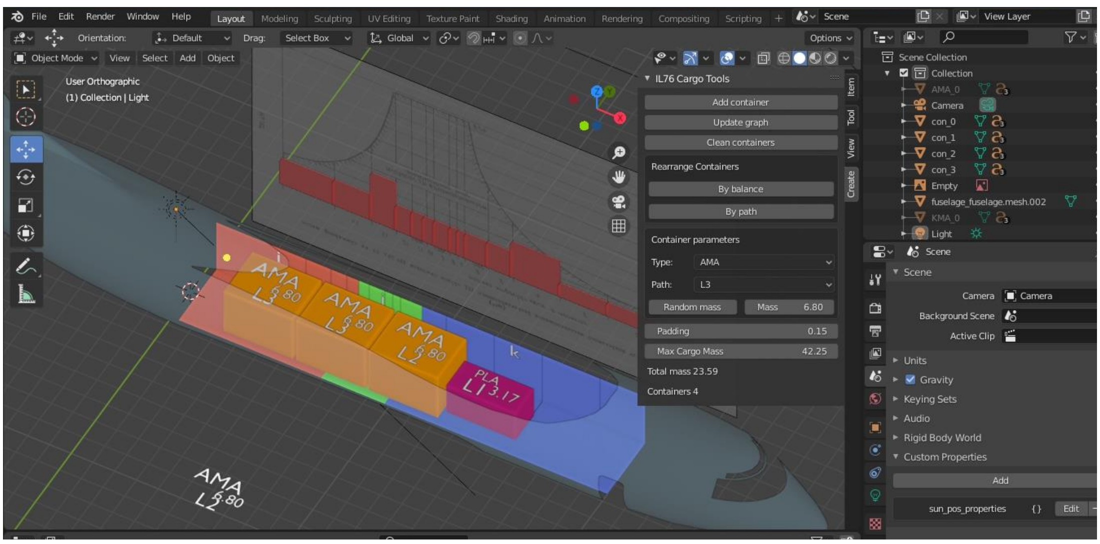

Fig. 8. Visualization of the model: Arrangement of additional containers in accordance with the requirements of the centering planning and loading scheme

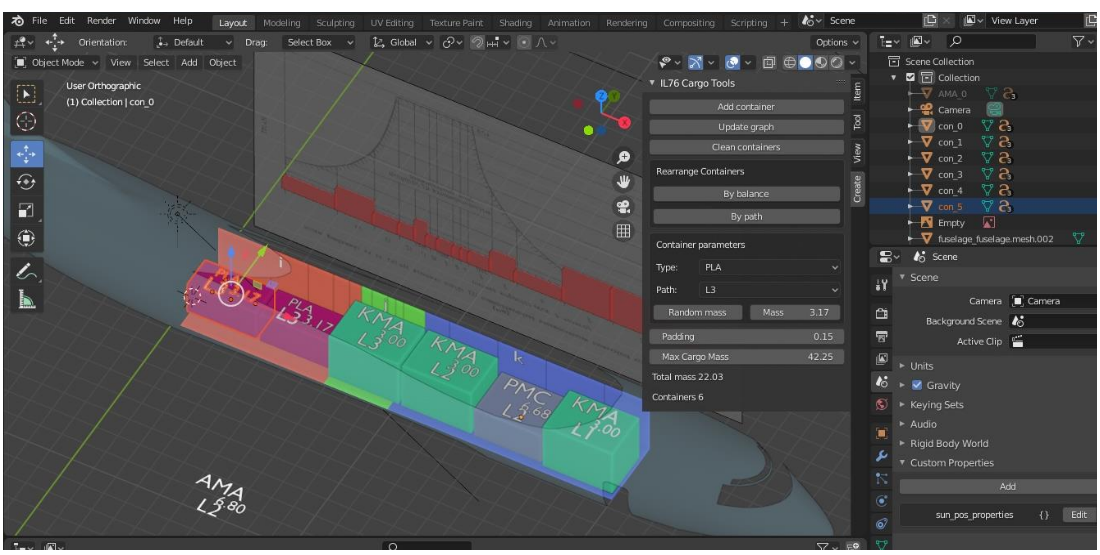

Fig. 9. Visualization of the model: The case when the parameters of the container do not correspond to the dimensions of the cargo compartment

The program avoids the situation when certain criteria and constraints cause sorting «manually» by all indicators, which, of course, is very time consuming in the context of the urgency of servicing the aircraft at the airport.

5. 3. Experimental verification of the effectiveness of the created computer model

Experimental data of Table 1 indicate a decrease in time indicators after the implementation of the model.

Table 1

Results of the experiment of planning the loading of the Il-76 aircraft for a number of Zet Avia flights

No.	Route	Actual number of ULD types of certain flights (PLA, PMC, AMA, A (KMA)	Loading time before experiment, min.	Loading time after the implementation of the algorithm, min.
1	OMAL-UTNN-UAAA	7	105	102
2	UAAA-UTNN-OMAL	5	87	81,6
3	OMAL-OMSJ-UTNN	4	90	85,4
4	OMSJ-OMAL	4	50	45
5	OMAL-OMSJ	3	50	45
6	UTNN-OMSJ-OMAL	6	115	105,6
7	UTNN-OMSJ	4	70	58
8	OMSJ-UAAA	5	75	59,4
9	OMAL-UKON-UTNN	7	90	73,8
10	UAAA-UTNN-OMSJ	7	100	100
11	OMSJ-UTNN-UAAA	7	105	95
12	OMDV-UTNN-UAAA	5	85	81
13	UAAA-UTNN-OMDV	6	90	89
14	OMRK-UAAA	3	44	41
15	UAAA-OMSJ	4	55	51
16	OMSJ-OMAL	3	56	50
17	UTNN-OMAL	4	60	56
18	UTNN-UKON-OMDV	7	90	83

Note: OMDV – Al Maktoum; OMSJ – Sharjah; OMRK – Ras Al Khaimah; UAAA – Almaty; UTNN – Nukus; OMAL – Al Ain; UKON – Mykolaiv.

A histogram of the experimental results during a certain series of flights in a double direction is shown in Fig. 10.

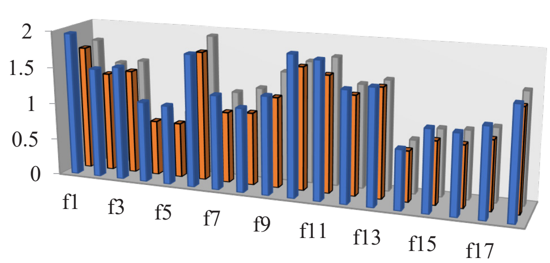

Fig. 10. Histogram of the experiment results on a number of flights

The histogram graph shows three different columns of data. The blue column indicates the experimental time before the implementation of the optimization model, the orange column shows the simulated time in the program, and the gray column represents the experimental load time after the model was introduced into the operation of the airline. As an example, it is possible to consider the multi-lag (several segments) route OMSJ – UTNN – UAAA (Sharjah – Nukus – Almaty). The duration of normal loading operations after the implementation of the optimization model was reduced by 10 minutes.

6. Discussion of the results of the influence of the computer model of loading planning on the time indicators of cargo servicing

Data of Table 1 indicate a decrease in download duration indicators. The results of the experiment show that the average time of loading/unloading operations on a number of direct flights decreased by almost 7 %, and on multi-lag flights – by 12 %. Reduction of time indicators (cargo handling) loading after the implementation of the algorithm and, accordingly, the visualization of the model follows from the fact that decision-making is based on the conditions laid down in the algorithm. These conditions make it impossible for ad-hoc loading «at random» or only according to the schedule in Fig. 2. Unlike the study [7], where only the limitations of the center of mass rectangle are taken into account, in this case, the main criterion is precisely the priority of unloading. Therefore, the algorithm shown in Fig. 3 and Fig. 4 returns the user to the previous step before the previous container from the same leg of the route is loaded according to all the restrictions in the airplane compartment. That is, a certain loading sequence is saved based on the specific documentary data of each flight. The principle of «stacking cargo», also described in the studies under study [6, 9], does not work in the conditions of a multi-lag route. The proposed decision-making algorithm helps the user (loading dispatcher or board operator) to avoid a situation when the cargo cannot be unloaded in a given route segment due to the fact that it is necessary to reload what is attached in front of it.

The heuristic component, which is based on data from expert experts, contains options for solutions that necessarily comply with the restrictions and the order of loading. With the help of specific planning decision algorithms, it is possible to control that the loading of a particular container correlates with the overall performance and physical constraints of the aircraft. This allows to go through all possible loading options in real time without wasting time, which will affect the speed of operations with direct loading and, in general, the turnover of the aircraft.

The computer model still has restrictions on the types of aircraft. That is, it should only be a ramp for cargo aircraft. For aircraft equipped with a ramp, such a solution is not advisable, since in such aircraft there is free access to all compartments (as a rule, there are several of them) and the problem of loading speed is solved due to the number of personnel in the handling service without involving software optimization solutions.

Disadvantages of the study may be exogenous factors affecting the time indicators of cargo handling (human factor and meteorological conditions, as an example, flight No. 10 UAAA-UTNN-OMSJ, Table 1). This situation can neutralize the speed of decision making on flight planning.

A three-dimensional computer model of load planning has all the necessary conditions and parameters for creating a rule-based expert system on its basis. The main practical task of such a system is to manage all flight data, since it is equipped with a database of general parameters of aircraft and their cargo sections, described in the form of positive integer data.

The visualized load planning computer model allows flight planning personnel to make decisions faster and predict additional load on other legs of the route.

7. Conclusions

1. The essence of the decision-making algorithm when planning the loading of a cargo aircraft is the location of groups of cargo relative to the cargo compartment, taking into account all the restrictions of the aircraft and taking into account the priority of the cargo. Placement options and load combinations are consistent with the general constraints and conditions of experts who investigated the impact of these decisions on the further development of the algorithm. Maintaining general restrictions on centering and priority of the cargo contributes to quick decision-making in planning and minimization of loading time in conditions of an indefinite amount of cargo and a multi-lag route.

2. Based on the decision-making algorithm for the planning of the load, a computer model of the load planning was created and visualized. The use of computer visualized models will provide air cargo carriers with the opportunity to adjust their efficiency indicators (speed of cargo operations) in real time and take into account the cargo appears on the apron almost in the last minutes before departure. This, in turn, contributes to the intensification of the use of the air carrier's aircraft fleet by accelerating commercial cargo handling and consistently reducing operating costs.

3. Using the method of peer review, it is determined that the experimental load time became less time in software optimization solutions, confirms the effectiveness of the model. The average time of loading/unloading operations on the flights of the investigated air carrier, on direct flights, decreased by 7 %, and on multi-lag flights – up to 12 %.

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