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CURRENT STATUS OF AIRCRAFT LOAD OPTIMIZATION PROBLEM

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Abstract

Purpose: *research of existing approaches to solve the aircraft load optimization problem and searching the perspective ways of improving the loading processes.* ***Methods****: heuristic methods, mathematical analysis, and modeling, linear and dynamic programming, constraint optimization.* ***Results****: the problem was found, which lies in neglecting of the time factor towards aircraft loading optimization.* ***Discussion****: Scientific literature contains researches towards assignment, bin packing problem, loading value (cost) minimization approaches. The cargo compartment's rectangle model gives an opportunity to optimize the payload's replacement towards the center of gravity, and also to find it's most appropriate position. Integrated objective function with time, weight and value constraints of aircraft loading process was proposed. Integrated aircraft loading process optimization will lead to decreasing of salary costs of the air staff, aircraft's turnaround time and airport charges.*

Keywords: aircraft load optimization; mathematical model; loading time optimization; objective function; ULD (Unit Load Devices)

1. Introduction

Air cargo plays a significant economic role in the society representing about 10% of world trade volume, it is more than $6.4 trillion annually [1, 2]. Optimizing loading assignment is extremely important for airlines because of several reasons. Firstly, correct loading determines safety. Secondly, optimal loading has a positive impact on aerodynamics, provides less fuel consumption, and minimizes costs and environmental effects. Thirdly, optimal loading is important for air companies in ground handling operation process, when the route consists from several legs and especially within time limits.

The scientific literature contains the following optimization researches:

1) Assignment problem – correct ULD's replacement inside the aircraft. Such problem often correlates with Weight and Balance problem.

2) Bin Packing Problem (BPP) – allocation f the items inside the cargo bin.

3) Heuristics:

Pyramid loading places the heaviest items close to the ideal CG adding item alternately toward the fore and aft of the aircraft.

50/50 method means that 50% of the cargo mass is placed on either side of the optimal cargo load.

Detailed analysis of the load optimization problem enables to make some suppositions:

1. The cargo assignment procedure is appropriate no matter which way the weight and balance is made. Inappropriate weight assignment can cause serious incidents such as side slope of the aircraft or the lift of the nose landing gears – the position called "candle" [6].

2. Even the slightest deviation from the ideal center of mass/gravity can increase the fuel consumption.

As an example, for an A340-300, a displacement of the CG of 750 mm from the ideal location along the longitudinal axis will lead to the consumption of an extra 4000 kg of fuel over the course of a 10,000 km flight. Thus, some airplanes, equipped with automatic fuel transferring still win from appropriate load planning [7].

While studying the alternative load optimization approaches, we defined some problems, linked with

Load & Balance and assignment; consequently, we analyzed different mathematic approaches to solve them. However, studied researches don't provide any example of the load optimization problem's solution inside the time frames. After all, the time savings depend on the quantity of loading/unloading operations.

2. Review of publications

It is important to note that there is a great diversity of topics behind the theme of cargo load planning [3].

The load optimization problem is an Assignment Problem found in literature as the family of Weight & Balance Problem s[4]. Limbourg et al. [5], we divide these researches into three categories. First, several types of research consist of load optimizing of cargo inside ULDs separately from the aircraft. This part especially connects with the Bin Packing Problem (BPP). The next important statement is ULD or item selection which has to be loaded in an aircraft or the cargo deck of the aircraft - Knapsack Problems (KP). Papers of this subject were studied by military works of Kaluzny and Shaw [6]; and commercial works (Mongeau and B`es) [7,8]; Fok and Chun [9], Gueret G. [10] and Nance R. L., Roesener A.G. [11].

The last category of authors deals with the location of ULDs in the aircraft. In this field of study, the literature is subdivided into two approaches: Bin Packing or Assignment. In the BPP approaches the authors seek to fill the aircraft non-stopping the way of excluding empty spaces between the items. Assignment Problem provides attempts to place ULDs into predefined determined positions.

3. The aim of the research

The aim of this work is the research of the existing approaches to the load optimization problem of the aircraft and searching of the perspective directions of loading process' development.

Research tasks:

- finding of the additional criteria to evaluate the load optimization problems;
- writing an objective function of the loading process with time, capacity, cost and weight constraints.

4. Load optimization approaches

One of the major contemporary approaches of load optimizing is demonstration of the cargo compartment as a rectangular model and defining the ideal center of mass with the aim to correct the ULD's allocation. ULD is an assembly of components consisting of a container or of a pallet covered with a net, whose purpose is to provide standardized size units for individual pieces of baggage or cargo and to allow for rapid loading and unloading [6].

The location of the center of mass $\vec{r}_{CM}$ is determined in the general case using the formula:

$$\vec{r}_{CM} = \frac{\int \rho(\vec{r})\vec{r}dV}{\int \rho(\vec{r})dV}, \quad (1)$$

where $\vec{r}$ – is a position vector;

$\rho(\vec{r})$ – is a function which describes the density distribution of the system;

dV – is the infinitesimal volume element over which the integration is carried out.

In case when the system consists entirely of point masses, then, $\vec{r}_{CM}$ may be calculated with the help of simpler expression:

$$\vec{r}_{CM} = \frac{\sum_i m_i \vec{r}_i}{\sum_i m_i}, \quad (2)$$

where m_i – are the means the mass of particle i.

Let's consider the aircraft cargo compartment as a rectangular model (Fig. 1), and point on it the cargo item as a small triangle (Fig. 2) [6].

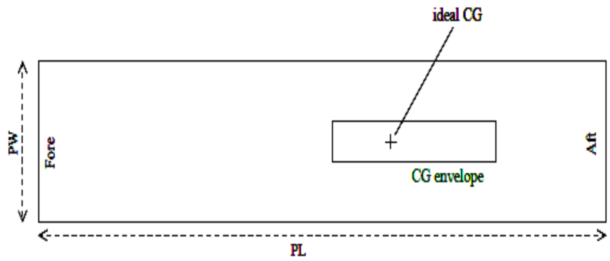

Fig. 1. Rectangular model of the aircraft's cargo compartment

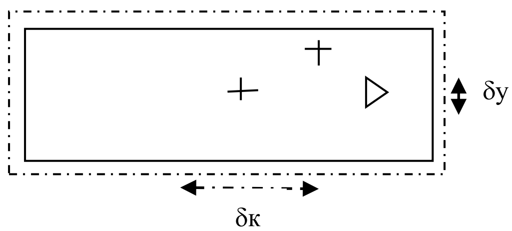

Fig. 2. Rectangular model of an item

The item – specific allocation means that models need some space between items and between items and walls of the cargo compartment. For example, for a 20 – foot bin will only be necessary six inches space from other items, but the truck requires a foot of clear space to create access for driver's door [12].

In case when the container and truck are placed side-by-side, the truck's spacing requirement is more relevant.

5. Objective function

For finding of the right approach to solve the load optimization problem we need to write an objective function which lies in minimizing of the loading time of set amount of the cargo bins.

Let, XR_{cg} and YR_{cg} stay x-coordinates and y-coordinates towards the aircraft's center of mass after loading.

Output function parameters:

δx_i – is a center of mass longitudinal deviation of i – bin from the ideal center of mass,

δy_i – is a center of mass latitudinal deviation of i – bin from the ideal center of mass.

T_{loadi} – is a loading time of the i bin to the aircraft;

$\mathrm{T_p}$ – is an aircraft's parking time at the airport;

P – is an aircraft's parking cost at the airport;

w_i – is a weight of the i-bin;

C – is a cargo compartment's capacity;

n – is a number of containers/bins.

The objective:

$$\min \sum_{i=1}^{n} T_{load_i}, \tag{3}$$

Subject to constraints:

$$1) \quad XR_{cg} \to 0, \tag{4}$$

$$\delta x_i \geq 0, \ \forall_i \in \{1,...n\}.$$

$$2) \quad YR_{cg} \to 0, \tag{5}$$

$$\delta x_i \geq 0, \forall_i \in \{1,...n\},$$

$$w_i \leq C, \ \forall_i \in \{1,...n\}.$$

$$3) \quad \min \sum_{i=1}^{n} T_{load_i} \leq T_p, \tag{6}$$

$$P \to \min, \ \forall_i \in \{1,...n\}.$$

While using the constraint optimization method, let the loading time minimization be the main criterion. The objective function was actually build based on this criterion.

The second criterion is minimization of the distance of the loaded plane's coordinates of the center of gravity from the plane's ideal center of gravity.

The third criterion is cargo compartment's capacity maximization.

Constraints of the objective function are:

– longitudinal and latitudinal deviation points towards the ideal center of gravity after the loading;

– cargo compartment's capacity;

– time and subsequently cost of aircraft's parking at the airport.

Studying of loading procedures and analyzing inside the time frames can lead to the further cut of labor costs per flight and subsequently reduce turnaround time (the time between the plane's landing on the runway and taking off again), also cut airport fees. The saved time and finances can be used for other operations.

6. Conclusions and directions for future research

Aircraft loading time optimization is critically important, as it directly influences on time and cost of loading/unloading operations.

An aircraft load optimization problem is performed as a multi-criteria task, which lies in loading time minimization.

Criteria for solving the load optimization problem:

1. Minimization of the loading time of cargo bins to the aircraft;
2. Minimization of the distance between the loaded plane's coordinates of the center of gravity and the plane's ideal center of gravity;
3. Maximization of cargo compartment's capacity.

The problem of loading time optimization is performed as a mathematical function with all feasible constraints. The perspective of solving such task gives the opportunity to examine the load optimization problem, considering the time constraints and the real example such as transportation of live cargo (animals).

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Сучасний стан проблеми оптимізації завантаження повітряних кораблів

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Мета: *дослідження існуючих підходів до вирішення проблеми оптимального завантаження повітряних кораблів та пошук перспектив напрямків удосконалення процесів завантаження.* ***Методи****: евристичні методи, математичний аналіз та моделювання, лінійне та динамічне програмування, цільова оптимізація.* ***Результати****: Виявлена проблема, яка полягає у відсутності врахування часового фактору при оптимізації завантаження повітряних кораблів.* ***Обговорення****: Наукова література містить дослідження з оптимізації розташування вантажу, вдосконалення його пакування, мінімізації вартості завантаження. Прямокутна модель вантажного відсіку дає змогу оптимізувати розташування комерційного завантаження відносно центру тяжіння, а також знайти його найбільш сприятливе положення. Автором запропонована комплексна цільова функція з часовими, ваговими та вартісними обмеженнями процесу завантаження повітряного корабля. Комплексна оптимізація процесу завантаження повітряних кораблів призведе до зменшення витрат на заробітну плату авіаційного персоналу, скороченню оборотності літаків та аеропортових зборів.*

Ключові слова: оптимізація завантаження; математична модель; оптимізація часу завантаження; ULD (засоби палетної обробки); цільова функція

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Современное состояние проблемы оптимизации загрузки воздушных кораблей

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Цель: *Исследование существующих подходов к решению проблемы оптимальной загрузки воздушных кораблей и поиск перспективных направлений усовершенствования загрузочных процессов.* ***Методы****: эвристические методы, математический анализ и моделирование, линейное и динамическое программирование, целевая оптимизация.* ***Результаты****: Обнаружена проблема, состоящая в отсутствии учета временного фактора при оптимизации загрузки воздушных кораблей.* ***Обсуждение****: Научная литература содержит исследования по оптимизации расположения грузов, усовершенствованию его упаковки, минимизации стоимости загрузки. Прямоугольная модель грузового отсека дает возможность оптимизировать расположение коммерческой загрузки относительно центра тяжести, а также отыскать его наиболее приемлемое положение. Автором предложена комплексная целевая функция с временными, весовыми и стоимостными ограничениями процесса загрузки воздушного корабля. Комплексная оптимизация процесса загрузки воздушных кораблей приведет к уменьшению затрат на заработную плату авиационного персонала, сокращению оборотности самолетов и аэропортовых сборов.*

Ключевые слова: оптимизация загрузки; математическая модель; оптимизация времени загрузки; ULD (средства паллетной обработки); целевая функция

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