# Automatic Cargo Load Planning

Sabine Limbourg[1],Michaël Schyns[1]*,Gilbert Laporte[2]

[1] QuantOM, HEC Management School, University of Liège,
Rue Louvrex 14 (N1), 4000 Liège, Belgium.
M.Schyns@ulg.ac.be,Sabine.Limbourg@ulg.ac.be

[2] CIRRELT and Canada Research Chair in Distribution Management,
HEC Montréal, 3000 chemin de la Côte-Sainte-Catherine, Montréal, Canada H3T 2A7,
Gilbert.Laporte@cirrelt.ca

## 1 Managerial goal

The goal of this research is the development of a mixed integer linear program for the optimal loading of a set of *Unit Load Devices* (ULDs) into a cargo aircraft. A ULD is an assembly of components consisting of a container or of a pallet covered with a net, whose purpose is to provide standarized size units for individual pieces of baggage or cargo and to allow for rapid loading and unloading. This problem is of crucial importance to airline companies for at least two reasons. First, aircraft loading is subject to safety constraints. Indeed, the stress imposed on the structure of an improperly loaded aircraft can result in the destruction of valuable equipment and ultimately in the loss of lives. Second, improper loading decreases the efficiency of an aircraft with respect to its altitude, manoeuvrability, rate of climb, and speed. An inappropriate load could even prevent the flight from being safely completed or even from starting. At the opposite, an optimal load should allow a reduction of the fuel consumption and, consequently, lead to a significant decrease in costs and in environmental impact.

The aircraft cargo loading problem is normally solved by *load masters* who use interactive graphical tools with drag and drop capabilities. This means the load master can generate several potential solutions whose quality is assessed by a set of indicators. This works well in practice but is time consuming. The solution typically satisfies the basic constraint but may be suboptimal. Load planning is often executed at the last possible time before the planes departure, which means that fine tuning is not always a practical option. This is particularly true for express delivery companies such as FedEx, TNT and DHL whose business model relies on timely operations. On any given day, the cargo loading problem is solved tens of thousands times worldwide ([1]).

## 2 Problem and model

The problem considered in this work is the optimal loading of ULDs of different types, contours and shapes in an aircraft. The set of ULDs to be loaded as well as the set of available positions are known before planning starts. The solution should be such that the *centre of gravity* (CG) of the loaded plane should be as close as possible to a recommended position determined for safety and fuel economy reasons. In addition the loading should be concentrated or "packed" around this central position. This is particularly important when the aircraft is not fully loaded. We propose an original approach for handle this feature, based on the moment of inertia. In addition to these basic constraints, a feasible solution must also satisfy other

*Speaker at ROADEF 2011

requirements. Each position can only accept some specific types of ULDs, depending on their contour, type and weight, the plane must be balanced longitudinally and transversally, the total weight concentrated at each inch and for each deck must be less than given thresholds (combined weight constraints), the cumulative weight at each inch from the front up to the middle of the plane must also be less than another threshold function (cumulative foward constraint) and a two-level threshold is also applied to the aft part (cumulative aft constraints). Because of the weight and CG constraints, the loading problem is sometimes called the "weight and balance" problem.

## 3 Literature

The scientific literature on aircraft cargo load planning contains a number of mathematical models and heuristics. It is important to note that there is a great diversity of topics behind the theme of cargo load planning (see [4]). In the subfield of ULD location problems, the papers by [3] and [5] are the closest to our work. However, they depart from our work on two important points. The first difference is about the set of constraints they consider, even if their model is clearly extensible. We have incorporated more realistic weight and balance constraints. The second and most important difference is about the objective function. Their main goal, before location, is a selection problem. They try, using different criterions, to find the optimal subset of ULDs to load in the aircraft before leaving the remaining ones for a next flight. [3] optimize the mass of goods loaded while [5] maximize the total cargo value. This also implies that the cargo is nearly always loaded at full capacity and that the freight is therefore naturally packed around the CG. At the opposite, our main goal is to load all the freight and to pack it around the CG even when the aircraft is not loaded at full capacity as it is often the case in practice [1].

## 4 Results

The scientific contribution of this paper is the development of an integer linear programming model for the aircraft load planning problem. The model can handle all constraints of the problem. We have also developed a software that takes as input all of the problems data and feeds them to the CPLEX integer linear programming solver through the proposed model. Tests were carried out on a set of real instances suggested by our partner : CHAMP Cargosystems. It is shown that feasible and optimal solutions can be reached within a few seconds. Our solutions were compared to those obtained by a load master and shown to be superior in every respect to those generated by experienced load master. Our paper [4] contains an exhaustive description of our mathematical model and the presentation of intensive numerical experiments.

## Références


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