

# AIRBUS



## AIRBUS QUANTUM COMPUTING CHALLENGE

Problem Statement n°5

### Aircraft Loading Optimisation

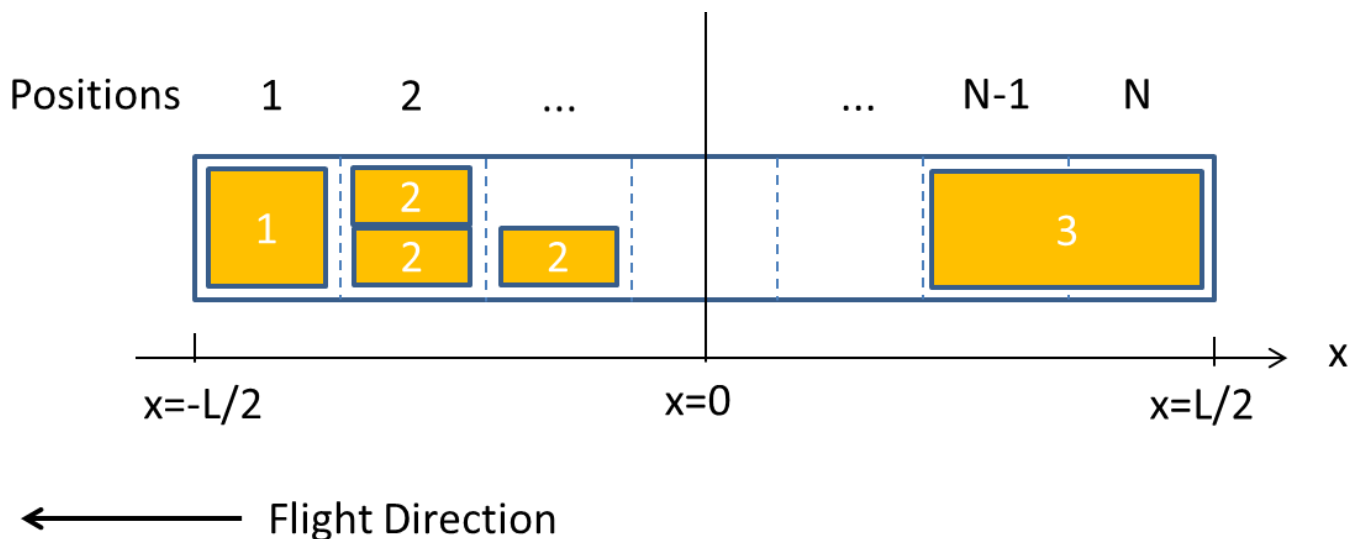


Aircraft Loading Optimization is about making the best choices on which parts of the available payload to take on board, and where to place them on the aircraft. An airline tries to make best use of the aircraft's payload capabilities in order to maximise revenue, and to optimise parameters with performance impact towards lower operating costs (fuel burn). The space for optimization is limited by the operational envelope of the aircraft, which must be respected at all times. The most notable limits here are the maximum payload capacity of the aircraft on a specific mission, the centre of gravity position of the loaded aircraft and its fuselage shear limits.

This problem statement describes a simplified representation of this class of problems, with stepwise implementation of the constraints and the associated optimization target. The overall objective is the practical demonstration of problem solving by use of quantum computing, and the robust assessment of scalability towards more complex problems.

## Problem description

A freighter aircraft has  $N$  positions for standard size cargo containers equally distributed along the fuselage main deck:



A set of  $n$  cargo containers of up to three different sizes is available for loading. Standard size containers (1) occupy a single position, half size containers (2) may share a single position, whereas double size containers (3) occupy two adjacent positions. Each container in this set has an individual mass  $m_i$ , which lies in between the empty mass and the maximum mass of each container type. Typically, the combined maximum masses of all containers exceed the aircraft's payload capacity.

## Step 1: Aircraft payload limit

Determine the subset of containers (from the set of  $n$  available containers with given mass and size) that **maximises** the mass of the carried freight for this flight.

It must be **physically possible** to place this set of containers on the aircraft, and the total mass of selected containers must not exceed the given **maximum payload** for this aircraft.

*A sample set of container types and masses is provided in the technical dossier.*

## Step 2: Aircraft centre of gravity limits

Determine the subset of containers that maximises the mass of the carried freight for this flight as in Step 1, and which can be allocated to container positions on the aircraft such that the **centre of gravity** of the fully loaded aircraft remains within given limits.

For this set of containers, **optimise the distribution** across the positions such that the centre of gravity position of the loaded aircraft is as close as possible to a given **target value**.

*Refer to the technical dossier for centre of gravity determination. A set of maximum, minimum and target values is given.*

## Step 3: Aircraft shear limits

Determine the subset of containers that **maximises** the mass of the carried freight for this flight and:

- Can be placed on the aircraft (Step 1)
- Does not exceed the **maximum payload** (Step 1)
- Allows for a **centre of gravity** position within limits (Step 2)
- Respects the **shear limits** on the aircraft fuselage (Step 3)

For this set of containers, **optimise** the distribution across the positions such that the centre of gravity position of the loaded aircraft is as close as possible to a given **target value**.

*The technical dossier contains an explanation of the simplified shear limits. A set of sample shear curves is given.*

## Path to solution for each step

1. Develop a suitable optimization algorithm which can be run on a quantum computer
2. Scalability: Assess how the performance would develop if  $N$ ,  $n$  and the number of container types were varied. Provide a statement on the number of qubits required for a certain complexity level.
3. Run a scale down version of the algorithm on existing quantum computing hardware or on digital quantum simulators and demonstrate its performance (maximum feasible values of  $N$ ,  $n$  and number of container types) **(bonus)**

## Assessment criteria/KPIs

1. Number of problem steps successfully completed
2. Performance of the algorithm: How close is the solution to the optimum solution (incl. worst case)? Both in general and for the given dataset.
3. Performance of the algorithm in terms of computation time on available quantum computing hardware or on digital quantum simulators performance (maximum feasible values of  $N$ ,  $n$  and number of container types) **(bonus)**

## Technical dossier

### Naming and labelling conventions:

The  $N$  positions on the aircraft are counted from 1 to  $N$ , beginning at the front of the aircraft.

A container available for loading is described by the triple (containerID, container type, container mass in kg). A set of  $n$  available containers for loading is thus a set of  $n$  triples, with the containerID ranging from 1 to  $n$ , and the container type ranging from 1 to 3.

A loading configuration allocates to each position either one, two or zero containers. In case of double size containers, two adjacent positions are being allocated the same container. Such a configuration can thus be represented by a set of  $N$  triples (position, containerID1 or 0, containerID2 or 0).

$L$	Length of the payload area on the aircraft
$W_p$	Maximum payload capacity of the aircraft in kg
$W_e$	Mass of the aircraft without payload in kg (ready for flight)
$W$	Mass of the loaded aircraft in kg
$x_{cg}$	Centre of gravity position of the loaded aircraft
$x_{cg}^e$	Centre of gravity position of the aircraft without payload
$x_{cg}^{min}$	Minimum allowed centre of gravity position of the aircraft (forward limit)
$x_{cg}^{max}$	Maximum allowed centre of gravity position of the aircraft (aft limit)
$x_{cg}^t$	Target centre of gravity position of the aircraft

### Centre of gravity position determination:

Only the  $x$ -coordinate of the centre of gravity of the loaded aircraft is relevant here ( $x_{cg}$ ). The containers may be considered as point masses with their centre of gravity being at their geometrical centre. The centre of gravity of the loaded aircraft  $x_{cg}$  is the combined centre of gravity of the empty aircraft  $x_{cg}^e$  (which is given and is within the limits) and of the centre of gravity of the set of distributed containers. There is a given forward ( $x < 0$ ) limit  $x_{cg}^{min}$  and an aft ( $x > 0$ ) limit  $x_{cg}^{max}$  for the centre of gravity position  $x_{cg}$  of the loaded aircraft.

### Shear definition and shear curve:

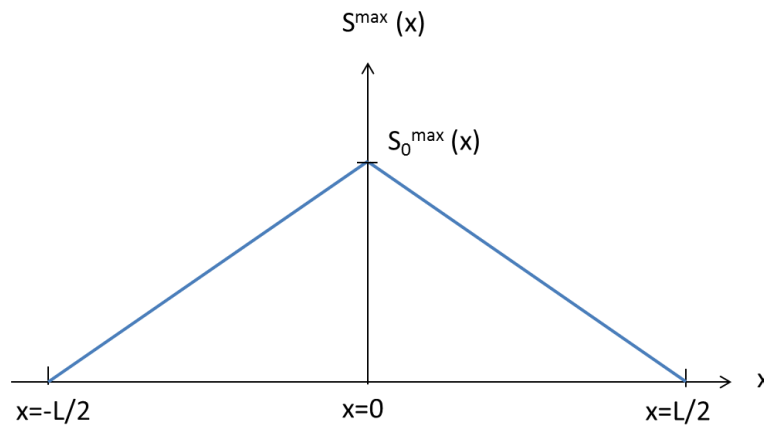
For this purpose shear  $S$  at position  $x$  is defined as:

$$S(x) = \int_{-L/2}^x m(x') dx' \quad \text{for } x < 0$$

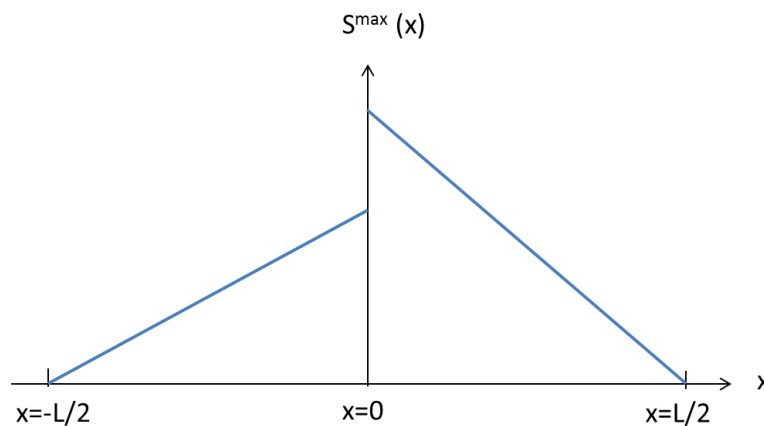
$$S(x) = \int_x^{L/2} m(x') dx' \quad \text{for } x > 0$$

With  $m(x)$  being the one-dimensional mass density of the payload. For a certain container position, the mass density is the total mass of the containers loaded on this position, divided by the length of the position  $L/N$ . It shall thus be assumed that the density of each container is constant along the flight direction. It is required that the shear  $S(x)$  remains below the so-called shear curve  $S^{max}(x)$  for all values of  $x$ . 3 shear curve types with the following characteristics may be considered successively:

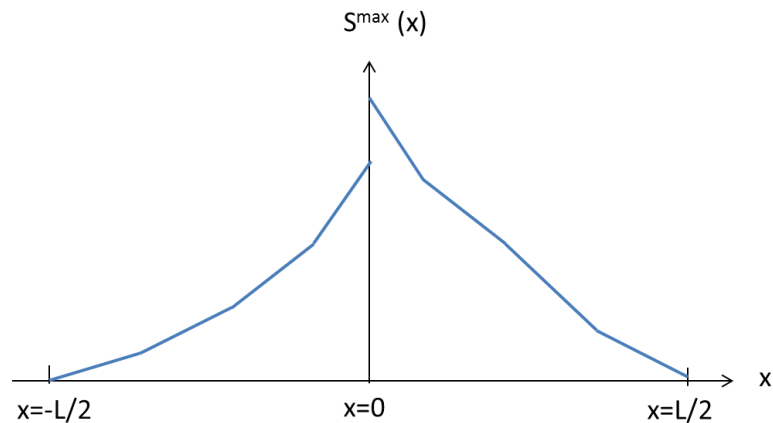
## 1. Symmetrical & linear



## 2. Asymmetrical & linear



### 3. Asymmetrical & nonlinear



#### Sample data set:

*This data set is for illustration and for testing the algorithm. The problem statement is not about finding the solution for this data set, but about developing methods to solve problems of this kind.*

$N = 20, n = 30, 2$  container types (1,2)

$W_p = 40000, W_e = 120000$

$x_{cg}^e = -0.05 L, x_{cg}^{min} = -0.1 L, x_{cg}^{max} = 0.2 L, x_{cg}^t = 0.1 L$

$S_0^{max} = 22000$  (shear curve type 1)

**Available containers for loading:**

Container ID	Container type	Container mass (kg)	Container ID	Container type	Container mass (kg)
1	1	2134	16	1	1566
2	1	3455	17	1	1765
3	1	1866	18	1	1946
4	1	1699	19	1	1732
5	1	3500	20	1	1641
6	1	3332	21	2	1800
7	1	2578	22	2	986
8	1	2315	23	2	873
9	1	1888	24	2	1764
10	1	1786	25	2	1239
11	1	3277	26	2	1487
12	1	2987	27	2	769
13	1	2534	28	2	836
14	1	2111	29	2	659
15	1	2607	30	2	765