Aircraft balancing is a process of high importance in the preparation of aircraft for a safe flight. There are four components that act on the aircraft in flight: the force of lift, the force of drag, weight and thrust. In order to insure safe aircraft take-off, a number of calculations need to be done. From the safety aspect, attention should be paid to maximum weight and aircraft limitations that are not to be exceeded. The total aircraft weight depends on the basic weight of the empty aircraft and the weight loaded onto the aircraft. If the aircraft is not within the defined limits, its structure is disturbed and this may cause serious danger, which may even have catastrophic consequences – aircraft crash. One more important factor needs to be mentioned, necessary for the aircraft safety, and that is the position of the centre of gravity in relation to the front and rear safety limit of the aircraft. The positions of the safety limits depend on the aircraft type and these should not be exceeded, since otherwise, the flight safety would be greatly endangered. The area in which the point of force is located depends on several factors such as: the number and position of baggage compartments which differ depending on the type of aircraft, and the previous calculations regarding aircraft loading, taking into consideration the load of each baggage compartment. Great importance for a safe flight lies also on the component of weight and arrangement of passengers in the cabin, as well as the total weight of fuel on board. For safe aircraft balancing, the principle of equalizing negative and positive momentums around axis y is applied. The moment y on the aircraft represents an imaginary line which passes along the wing span. In practice there are methods which are used to bring the aircraft into a safe flying position. This work will describe the procedures used to bring the aircraft into a safe flying position, as well as the influences of correct loading of aircraft on the flight safety.

Keywords
Aircraft balancing, flight safety, maximum aircraft load, dangerous goods, aircraft balancing methods

1. INTRODUCTION

Four aerodynamic forces act on the aircraft in flight: lift, drag, thrust and aircraft weight which interact. The force of lift annuls the aircraft weight, and the force of thrust annuls the force of drag. The force of lift occurs on the aircraft wings, and it may be said that the wings are the bearing area, and with its design and greater curvature of the upper surface, the wing creates the difference in pressures. The increase in the air stream speed over the upper wing surface creates the force of lift which moves the wing upwards. If necessary, the force of lift can be increased by equipping the aircraft with ailerons and flaps, as well as by increasing the wing angle of attack. The aircraft weight is the opposing force to the force of lift, and represents the total mass of the aircraft and corresponds to the Earth gravitation force. For moving through air, the aircraft requires the force of thrust defined as the force which is generated by the aircraft engines. The occurrence of the force of thrust causes drag. Apart from the mentioned forces, the momentum of force acts also on the aircraft in flight. Momentum is the combination of force and moment arm. To balance the aircraft it is important that the sum of the momentums, on y axis equals zero. Axis y is an imaginary line which passes along the wingspan. If the front part of the aircraft has the dive momentum, we speak of negative momentum, and if it has the momentum of ascent, we speak of positive momentum. Along y axis, the aircraft is affected by the distribution of cargo loaded onboard and moving the centre of gravity forwards or backwards. For the momentum to equal zero, it is necessary to calculate the position of the centre of gravity expressed in percentages of Mean Aerodynamic Chord, and marked %MAC.
2. INFLUENCE OF AIRCRAFT WEIGHT ON FLIGHT SAFETY

2.1 ACTUAL AIRCRAFT WEIGHTS

Aircraft weights are divided into actual weights and maximum weights. Actual weights include: MEW - Manufactures empty weight – total weight of the aircraft as delivered to the customer, and including the weight of the aircraft structure, engine, equipment in the passenger cabin and the very systems onboard aircraft), BEW - Basic empty weight – total weight MEW and weight of unused liquids onboard aircraft such as fuel and lubricant, potable water. The standard weights include also BW - Basic Weight – which is the result of the summary of the total weight BEW and weight of operative equipment not included in BEW, referring to the equipment that can be changed from flight to flight.

During aircraft handling operations, i.e. loading and adding fuel actual weights occur which also belong to real weights. These weights are: AZFW - Actual Zero Fuel Weight, which is obtained by summing dry operative weight and total loaded cargo, ATOW - Actual Take-off Weight, which is the result of the sum of the values of actual weight ZFW and fuel, and ALAW Actual Landing Weight, which is the result of the difference between the actual weight TOW and travel fuel, AZFW, ATOW, ALAW are the above described actual weights which must not exceed the maximum permitted values. The calculated actual weights for single flight are used by the crew for their calculations.

2.2 OPERATING AIRCRAFT WEIGHTS

Operating aircraft weights are used for the re-calculation of aircraft balancing, and as verification of exceeding the maximum permitted weights. Operating weights are: DOW - Dry Operating Weight which consists of aircraft weight, crew weight, their luggage, food, beverages for the flight. DOW changes in relation to the flight character and number of crew members. Along with DOW there comes also DOI (Dry operating index) which is used as the origin for calculating the aircraft centre of gravity. DOW and DOI are read from the manuals issued by the airlines. The total traffic load is the sum of the weight of payload onboard aircraft (passengers, luggage, goods and post). There is also OW – Operating Weight – which is the weight DOW and additional volume of fuel required for the aircraft flight.

2.3 MAXIMUM AIRCRAFT WEIGHTS

Maximum aircraft weights which represents the safety limits of aircraft are: maximum design ramp weight (MDRW) – highest structural weight of aircraft at apron. Under this load the aircraft is not allowed to move even by the power of their own engine nor using ground means. This weight is not to be exceeded due to structural restrictions of aircraft strength. Maximum design taxi weight (MDTW) – is the weight at which the aircraft movement is allowed on the apron powered by their own engines or some other towing or pushing vehicles. Maximum design take–off weight (MTOW) is maximal aircraft weight at which it may safely take off. The difference between these weights and design taxi weight are that in this weight is the consumed fuel for taxiing to the runway. Maximum design zero fuel weight (MZFW) – maximum aircraft weight up to which aircraft can be loaded by cargo. If we consider the wing statically, it represents the console which is on the one side attached to the hull, and on the other side free. The maximum wing load occurs due to the action of aerodynamic forces. This load acts so that the wing bends upwards. The second load that acts on the wing is its weight, which bends it downwards. The highest load will occur on the wing and hull connection at the moment when the aircraft is landing, and not taking off, regardless of the fact that the aircraft weight in takeoff is higher than the landing weight. The exceeding of this weight causes structural damage on the wing and hull fillets. Such damage is also called "wing folding". Maximum design landing weight (MLW) – the highest design weight of the aircraft in landing. Exceeding of this weight causes damage to the landing gear and aircraft hull. None of the mentioned maximum weights is to be exceeded. Exceeding of this weight results in the disturbance of the aircraft structure, which is not immediately visible, but over time under load it increases and this may jeopardize the flight safety.

3. IMPACT OF THE AIRCRAFT CENTRE OF GRAVITY ON THE FLIGHT SAFETY

The body centre of gravity is the point which accommodates the force resultant acting on this body in the field of gravity force. It may be said that this point combines the total body mass, i.e. the system of material points. The centre of gravity of the system is determined in the coordinate system which expresses the positions of single centres of gravity of the mass of
material points, for each weight in the given system. Flight performance will depend on the position of the aircraft centre of gravity. If the aircraft centre of gravity is more towards the front, the aircraft will feature the following momentums: for the change of the angle of attack it will be necessary to act with great force on the aircraft control handle, which is a sign that the aircraft is very stable longitudinally, and very difficult to steer. Also, with such centre of gravity, it is difficult to achieve the highest lift coefficient required for landing, so that the aircraft will have higher speed in landing than the speed it would have had to realize according to its characteristics. The landing speed increase can substantially jeopardize the flight safety in a certain manner. Similar thing is in take-off since the aircraft will have difficulty to lift off the ground and this may also jeopardize the take-off. In take-off the aircraft will need higher speed and longer runway. Regarding cruising, the aircraft balanced in such a way, will require corrections (trimming) in order to ensure horizontal flight and thus relieve the control handle. In this flight regime, additional aircraft drag is generated thus increasing the fuel consumption. If the aircraft centre of gravity is located more to the rear part, the aircraft will feature the following characteristics: small movements of the control handle will substantially change the angle of attack of the wings. This is a sign that the aircraft has low longitudinal stability, but is on the other hand easy to steer. The correction (trimming) itself is small or unnecessary when the centre of gravity is in the rear part, thus achieving better flight configuration and reduced fuel consumption. Only the centre of gravity shifts during flight, for various reasons. In aircraft with swept wings, due to fuel consumption, the centre of gravity of the remaining fuel shifts, thus changing also the aircraft centre of gravity. The retraction and extension of the landing gear also changes the centre of gravity of the entire aircraft during the take-off and landing phase. Movements of the crew and passengers during the flight, affect the change of the aircraft centre of gravity, as well as serving of food and selling of duty-free goods to passengers.

by which the position of the aircraft centre of gravity is calculated by means of a coordinate system. In the coordinate system the momentums of all the weight-measurable systems are calculated and then divided by their own weight. By multiplying the weights of the system and the moment arm at which it acts, we obtain the material point (CG) of the system. The first step is the calculation of the weight of each single element of the empty aircraft, and later also of every loaded cargo.

The second method is the so-called "index method". This is the method which uses the introduction of the index (term for dimension-free integer), to eliminate the possibility of errors in calculation. The index is a converted momentum, a number that represents the moment, and in combination with the aircraft weight it determines the position of the centre of gravity. The index method is based on indices which are read from the tables. Every carrier – airline determines the initial index (DOI or BI) for single aircraft in their fleet.

The third method is the graphical method which uses the procedure of eliminating the possible errors in calculation, but the procedure is not so precise as in case of the index method. For the graphical procedure, it is necessary to divide the loading aircraft spaces, including the passenger cabin and the fuel tanks into compartments. Every aircraft has its centre of gravity. The more we move toward the front of the aircraft, the more the negative momentum increases, whereas the positive momentum increases if we move towards the rear. Graphical presentation of the centre of gravity position is more frequent than the index presentation. The drawback is the lack of precision in plotting which occurs due to plotting using a ballpoint pen on a relatively small diagram. Consequently the reading of the values is less precise.

5. LOAD PLANNING AND LOAD INSTRUCTION DEVELOPING

Planning of loading is based on collecting of data that refer to cargo and post. The entire loading into the aircraft is planned in such a way as to not endanger the maximum values, i.e. capacities of the aircraft cargo spaces and that the balancing conditions are within the safety limits. For every performed loading it is necessary to leave space for possible adding or removing of cargo, keeping the aircraft within safety limits. Every loading has to contain a draft of the aircraft design per compartments, a part for the instruction on unloading/loading and special procedures and a part for the report on the performed loading. The Loading Instruction Report is a certificate that the aircraft was loaded according to the loading instructions, and it consists of a heading, general information, instruction for loading and report on loading. The heading contains the basic data about the flight such as the flight number, aircraft registrations, date, destination and departure time. The space for general information consists of the compartment code, distribution of a certain cargo or ULD, and the compartment volume. Since loading is performed after having received the
CARGO MANIFEST, the compartments contain exact values of goods and post, whereas luggage is entered as planned, depending on the booking. Every loading instruction has a space for special instructions into which special loading requirements are entered. This box contains warnings related to the condition of equipment and fixing in the aircraft. The last item is the loading report which represents a report on cargo details in single aircraft compartments. In case the permitted weights are exceeded, the landing gear may be damaged, a situation that the wings themselves are not able to create enough lift to lift the too heavy aircraft, and structural damage that are caused by exceeding the floor loading capacity of the deck onto which the cargo is laid. The aircraft structure is most sensitive at wing and hull fillets and every excess of the permitted weights affects primarily that part. In the distribution of luggage, goods and post per aircraft compartments, one should be careful not to exceed the maximum permitted hold capacity weights. It is also important to respect the company requirements about the loading and separating the luggage. Regarding separation of luggage per holds, one should take care of dangerous goods which can be loaded onto the aircraft, and the separation of these because of the possible interaction. All information on handling dangerous goods can be found in the handbook IATA DGR (IATA Dangerous Goods Regulations). Notification to Captain which informs the captain that dangerous goods will be loaded onto the aircraft and that it requires special conditions of transport. Finally, EZFW is calculated, which is obtained by summing the DOW with the planned weight of the passengers, their luggage and the actual weight of goods and post. This data allows the captain to determine how much fuel is to be loaded onto the aircraft.

Figure 3. Loading Instruction / Loading Instruction Report

6. DIAGRAM OF BALANCING

The diagram of balancing or the trimsheet is on the right side of the Loadsheet. The diagram is made by entering at the beginning Dry Operating Index from the airline manual, and the maximum weight. Then the weights of the cargo, luggage and passengers are entered into the provided boxes that mark the loading compartments for cargo and passenger sections. Drawing the lines towards baggage holds starts from the point which has been determined by the Dry Operating Index, and the line is drawn from the intersection of the point of the first box to the intersection of the point of the next box, where the first next weight has been entered. In this procedure one has to take care of the already pre-defined arrows on the right side of the document, which tell us in which direction we have to move across the diagram, depending on the position of the baggage hold and the cabin index. This procedure is repeated all the way to the place which contains the data on fuel correction which is read from the airline handbook, which contains the corrections for certain amounts of fuel. In entering the data on correction, two parallel lines are drawn vertically across the diagram, one of which shows the value without fuel correction, and the other is the corrected one. Lines are drawn to the y axis that mark the aircraft weight. After entering the lines we follow their intersection, by looking at where the vertical line is intersected without the correction of fuel and ZFW, and the vertical line with fuel correction and TOW. The procedure that follows is the reading of values %MAC for their intersections. At the very end it is important to note that the obtained values always have to be within the shaded part of the diagram in order to satisfy the flight safety condition.

Figure 4. Loadsheet / Trimsheet

7. COMPUTER LOADSHEET DEVELOPMENT

The principle of generating the loading instruction using computers is much simpler and faster since the computer automatically performs the calculation of all the weights and has input safety limits, to which it reacts automatically as soon as they are exceeded. The loadcontrol module is, namely,
connected to the cargo service, check-in and the sorting area. These three services enter directly the data into this module and enable the balancer to perform correct loading. The procedure is as follows: first, basic data are entered – aircraft registration, the booking is checked as well as the number and structure of passengers which is important for the distribution of luggage per aircraft compartments.

The actual weight of goods and post is entered and by means of the index on the computer, the optimal loading solution is found, of course, taking into consideration all the company rules. The module has also the option of assisting the balancer how to perform ideal loading and guides the balancer according to the indicators, which hold can accommodate more cargo so that the aircraft balance would be ideal. The completed LIR is printed.

Before inputting the data into the computer, the check is performed regarding the threat to the maximum value of the aircraft weights valid for the respective flight, exceeding of the surpassed zapreminske vrijednosti capacity value, overloading of certain cargo holds, the position of the aircraft centre of gravity is checked to see whether it is within the permitted limits and that all the data necessary for safe aircraft flight performance are entered into the system. After having collected all the information, the loadsheet and trimsheet of the aircraft are completed. All the changes regarding cargo weight onboard aircraft as well as in the area of fuel weight in the aircraft tanks, that occur after having completed and issued the loading lists are considered last-minute changes (LMC). In entering LMC, one should take into consideration that maximum permitted weights applicable for the particular aircraft are not exceeded, that the limitations of weight values in particular cargo compartment are not exceeded and that the aircraft centre of gravity remains always within the permitted limits. Every airline has a regulated maximum weight of LMC. The final values of weights and indices can be distributed via wireless links directly to the platform (or to the aircraft), more precisely, to the pocket PC (PDA) which is used by the ramp agent next to the aircraft. This solves then the communication and information of the ramp agent, i.e. aircraft captain about the weights, trim and other information about the aircraft itself.

CONCLUSIONS

Regarding the continuous increase in air traffic, the objective of the airports is faster, safer and higher quality of aircraft handling. Today, when computers have replaced the manual calculations, we speak of full implementation of information technology of air traffic, not because of the legal regulations, but for safety reasons, with the limits increasing from day to day. Load control service is precisely the service which sets the limits to high standards without which the aircraft handling would not be possible, and is at the same time one of the services responsible for fast and high-quality aircraft loading. Since every possibility of exceeding the permitted weights or wrong loading is fatal and jeopardizes the flight safety, load control, with the introduction of information technology regarding reduction of errors to minimum, with good staff may compete even with the highest demands of air traffic.

REFERENCES