

METHODS FOR EVALUATION OF AIRCRAFT MASS DISTRIBUTION

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Abstract

This paper presents the efforts for method and tool development for the calculation of aircraft mass and inertia distribution. This study is a part of an overall automation and tool development efforts for aircraft weight activities. One of the weight activities is the development of aircraft mass model for static and dynamic analyses. The development of aircraft mass model is performed using aircraft Computer Aided Software (CAD) model by slicing the structural and system parts to generate lumped masses along aircraft components. Traditional methods to calculate this mass distribution solely depends on CAD software, which becomes more time consuming and unfeasible as aircraft model becomes more complex during detailed design phases. In order to increase speed and reduce human error while maintaining full accuracy and fidelity, new methods and tools are developed to calculate the mass distribution and prepare the aircraft mass model.

1 Introduction

During the aircraft design projects, the weight properties of the aircraft is one of the most critical data, which has significant effect on each parameter varying from performance to structural stresses. The weight group, being strongly connected with other groups, calculates, manages, records and supplies the weight data of the aircraft.

The weight data of the aircraft not only includes the overall mass, inertia and center of gravity, but also the mass and distribution of the aircraft.

The mass distribution of the aircraft is used in static and dynamic analyses. The loads and structural dynamics groups use the aircraft mass and inertia distribution in their structural loads and aeroelastic calculations. In these analyses the aircraft mass model, which consists of lumped masses is used. The mass model includes not only structural masses, but also the payloads, fuel, systems and other non-structural items [1].

During the detail design phase, which is the longest phase of the aircraft design [2], the analyses are expected to be performed with all details to represent the actual physical condition with full fidelity. Therefore, main objective becomes to generate the fully accurate mass model with minimal assumptions and approximations.

However, the preparation of mass model with such detail involves with other weight activities to use the most recent weight data. Thus, the overall weight activities must also be taken into account, in order perform calculations with maximum detail and accuracy.

2 Overview of Weight Activities

It is critical to evaluate and use the most recent weight data during design phase of the aircraft. Therefore some efforts were put for development of tools which enable performing weight and balance activities in a more automated and controlled manner [3]. The weight activities are grouped in mainly four groups, such as,

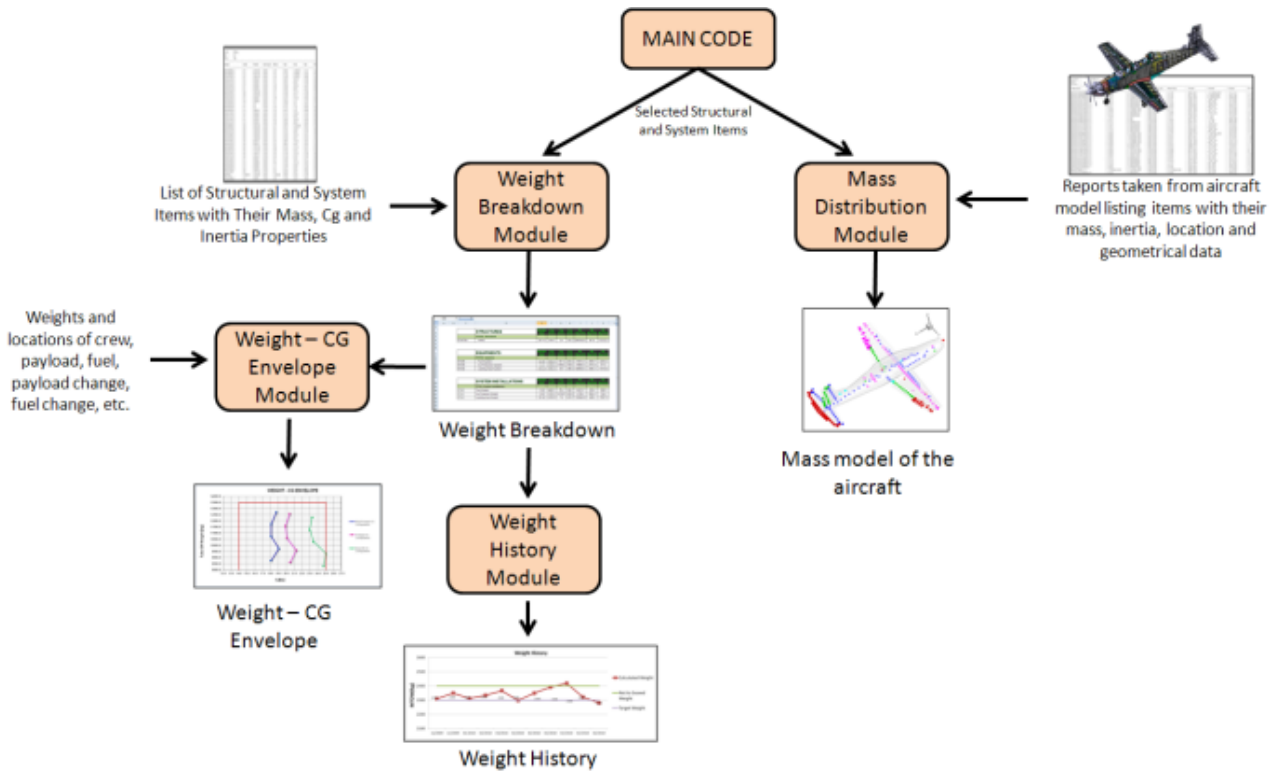


Fig. 1. Overview of Weight Activities with Input - Output Relations

- Preparation of Weight Breakdown
- Monitoring the Weight History
- Preparation of Weight – Center of Gravity (CG) Envelopes
- Mass and Inertia Distribution

The structure of weight activities with input and output relations is shown in Fig. 1. The tools are developed with graphical user interfaces (Fig 2.) and reporting and formatting features to help the weight engineer to perform weight activities easily.

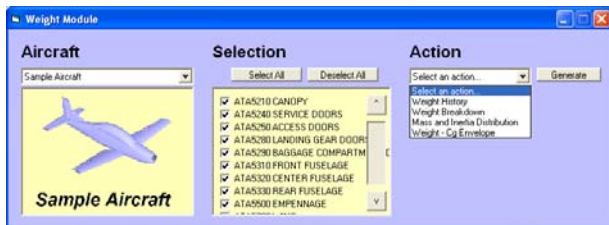


Fig. 2. Main Menu of the Weight Module

These activities can be detailed in following sections.

2.1 Weight Breakdown

Weight breakdowns are prepared in all phases of aircraft design to present the weight properties of each structural parts, equipments and system installations. [4] The preparation of the breakdown requires most updated weight data from bulk data of structural and system items of the aircraft, taken from Product Lifecycle Management (PLM) software and aircraft CAD model. A simple example to a weight breakdown can be shown in Fig. 3.

	Weight (kg)	Xcg (mm)	Ycg (mm)	Zcg (mm)	Mx (kg.m)	My (kg.m)	Mz (kg.m)
STRUCTURES							
TOTAL Structural							
ATA3700	397.14	5194.7	2.4	-335.2	2063032.6	957.8	-133123.5
EQUIPMENTS							
TOTAL Systems							
ATA20	16.06	4584.0	-187.4	-253.4	73615.9	-3009.7	4239.2
ATA30	0.13	5309.2	-1300.5	143.9	10993.8	-2772.9	317.5
ATA32	195.10	4795.0	-52.6	-389.2	929842.3	-2466.3	-76734.8
SYSTEM INSTALLATIONS							
TOTAL System Installations							
ATA20	3.08	4522.5	-76.4	-324.7	14219.7	-235.2	998.9
ATA30	0.08	4762.5	-4190.5	209.0	4198.4	-3694.5	-184.2
ATA32	32.34	4729.9	-7.0	-216.7	152945.0	-226.5	-7007.8

Fig. 3. A Typical Weight Breakdown of Selected Components and Systems

2.2 Weight History

During the design of an aircraft, keeping the track of the weight changes of aircraft is required for weight management. As the weight breakdown is prepared automatically, the weight history of both separate systems and structures and overall weight information is recorded. [5]

With the automatic preparation of weight breakdown, the results are also recorded after each modification or update. Those recorded weight values can be accessed directly and the plot showing weight variation with time is prepared automatically. An example to a typical weight history can be shown in Fig. 4.



Fig. 4. Example of a Weight History

2.3 Weight – CG Envelope

Preparation of weight and CG envelopes, which involves information about the payloads, crews and mission profile as well, is critical in all phases of aircraft design. These envelopes are also supplied to flight test groups to ensure that the center of gravity of the aircraft stays within the limits. To make sure that the aircraft weight and cg values stay within the limits during the flight, the lines are drawn starting from takeoff to landing showing weight and CG path [6], [7]. Such a Weight – CG envelope can be seen in Fig. 5

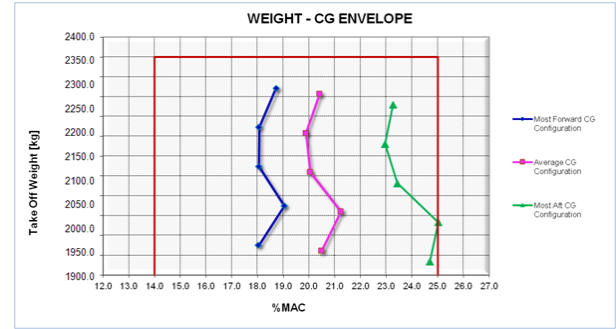


Fig. 5. Sample Weight - CG Envelope

2.4 Mass and Inertia Distribution

As stated in previous chapters, the mass and inertia distribution of the aircraft is prepared to provide input for static and dynamic analyses. The evaluation of mass and inertia distribution of the aircraft, which involves the complete model of the aircraft, is one of the most tiresome activities. The Weight Module prepares the mass model with the methods detailed in this study.

The results of mass distribution can be visualized in Fig. 6. After the mass distribution activities, output files such as CONM2 card files, are generated which are directly compatible to CAE software like NASTRAN. (Fig. 7)

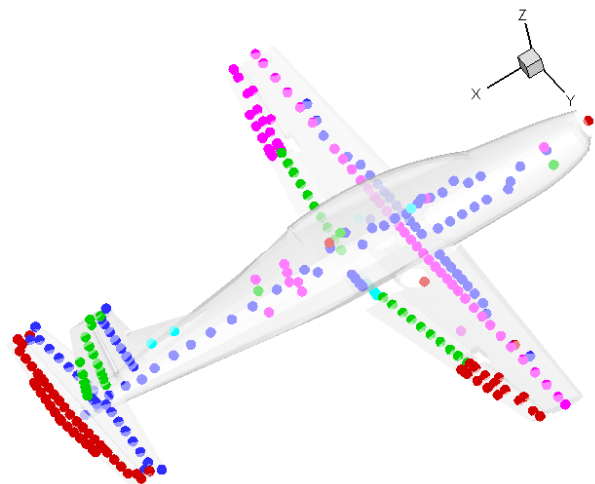


Fig. 6. Visualization of Lumped Masses Generated by Weight Module

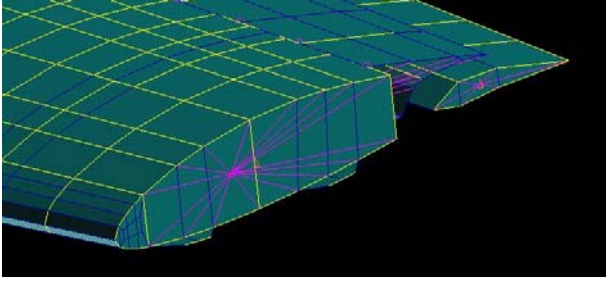


Fig. 7. Output of Mass Distribution Activities

3 Properties of Aircraft Mass Model

The preparation of mass model to be used in Finite Element Analysis (FEA) software starts with definition of lumped masses. Those lumped masses are usually selected at sectional elements along the aircraft component such as ribs and frames. Then, the lumped masses are connected to the structural hard points [8]. Those structural hard points are usually the intersection of ribs and spars or skin and ribs. The reason why the hard points are chosen to connect the lumped masses is to prevent local normal modes. For instance, in NASTRAN, the lumped masses, which are defined on non-structural grid points, are connected to hard points with RBE3 elements. An example of application of lumped masses to a finite element model is illustrated in Fig. 8.

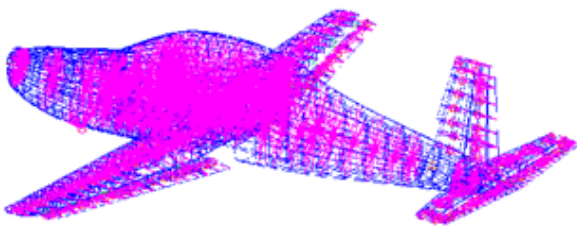


Fig. 8. Mass Model Consisting of Lumped Masses Attached to Finite Element Model for FEA Software

4 Mass Distribution using CAD Software

Most CAD software enables user to slice the geometrical models and calculate the mass and inertia parameters of the slices. The traditional way to evaluate the mass distribution of a component or the aircraft is slicing of the CAD

model of the aircraft with CAD software and recording the mass and inertia values of each slice. This procedure can be outlined in Fig. 9.

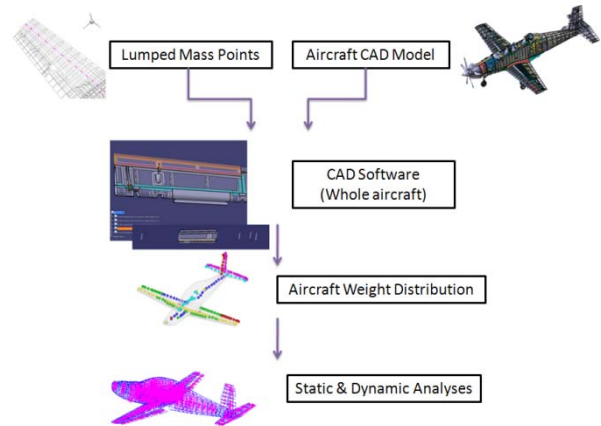


Fig. 9. Mass Distribution Procedure with Slicing CAD Model Manually

Using the locations of lumped masses, the slicing planes are created along the aircraft components. Those planes are then used to slice the CAD model of the components. The typical application of this slicing operation with CAD software can be illustrated in Fig. 10.

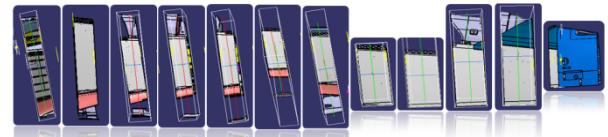


Fig. 10. Slicing the CAD Model of an Aircraft Component using CAD Software

Although the procedure is straightforward, it is not feasible to use this method with detailed CAD models of the aircraft. As detailed design phase of the aircraft goes on, the number of structural and system items exceed thousands in the aircraft model.

Working with such large and complex models can be beyond the capabilities of CAD software or computational power. Even the model can be opened in CAD software, it works slow and problematic with models consisting thousands of sub-assemblies and parts. Also being a manual process, several human errors may arise.

5 Automation Efforts

Because of the problems regarding the traditional method of calculation of mass distribution, some efforts were put forward to automate the process. The main objectives of these efforts are to increase speed and decrease human error while maintaining the full accuracy.

The developed method uses the lists of mass, CG, inertia and geometric properties of all structural and system items as the main input. These structural and system items are assigned to lumped mass sections according to their locations.

However, it is not always possible to assign a CAD item to a single mass point. These items are generally long structural parts and some parts intersecting the slicing planes between the mass points. These items may be assigned to the mass points according to their cg locations, but the errors are considered to be unacceptable. (Fig. 11)

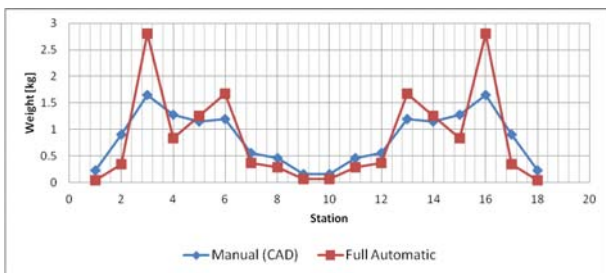


Fig. 11. Mass Distribution of a Lifting Surface: Comparison of Manual and Fully Automatic Methods

Also, the parts, which cannot be assigned to a single mass point, may be analytically sliced with some assumptions such as constant cross-section. However, the assumptions reduce the

fidelity of the analyses which is not desirable during the detail design phase. Thus, such assumptions are also not accepted for the sake of full accuracy of analyses.

6 Hybrid Method for Full Accuracy

The accuracy level of above mentioned automated method is not considered satisfactory; therefore it was decided to introduce a hybrid method. With this method, the program recognizes the items which are either too long to be assigned to a single mass point, or large items intersecting the slicing planes between the mass points. These items are excluded from the automatic process and separated for slicing in CAD software. The slices of these items are then combined with remaining items to be assigned to lumped masses. The flowchart of process is shown in Fig. 12.

For common aircraft components, the number of the parts, which undergo the slicing operation using CAD software, usually consists of 10 to 20 percent of all the structural and system items. Therefore, the disadvantages of traditional method with solely depending on CAD software are reduced.

With the only main input of the procedure is the list of structural and system items, the mass distribution process becomes more controllable and integrated with other weight activities.

The mass distribution, on the other hand, is evaluated with full accuracy (Fig. 13). This is important for static and dynamic analyses to be performed with full fidelity

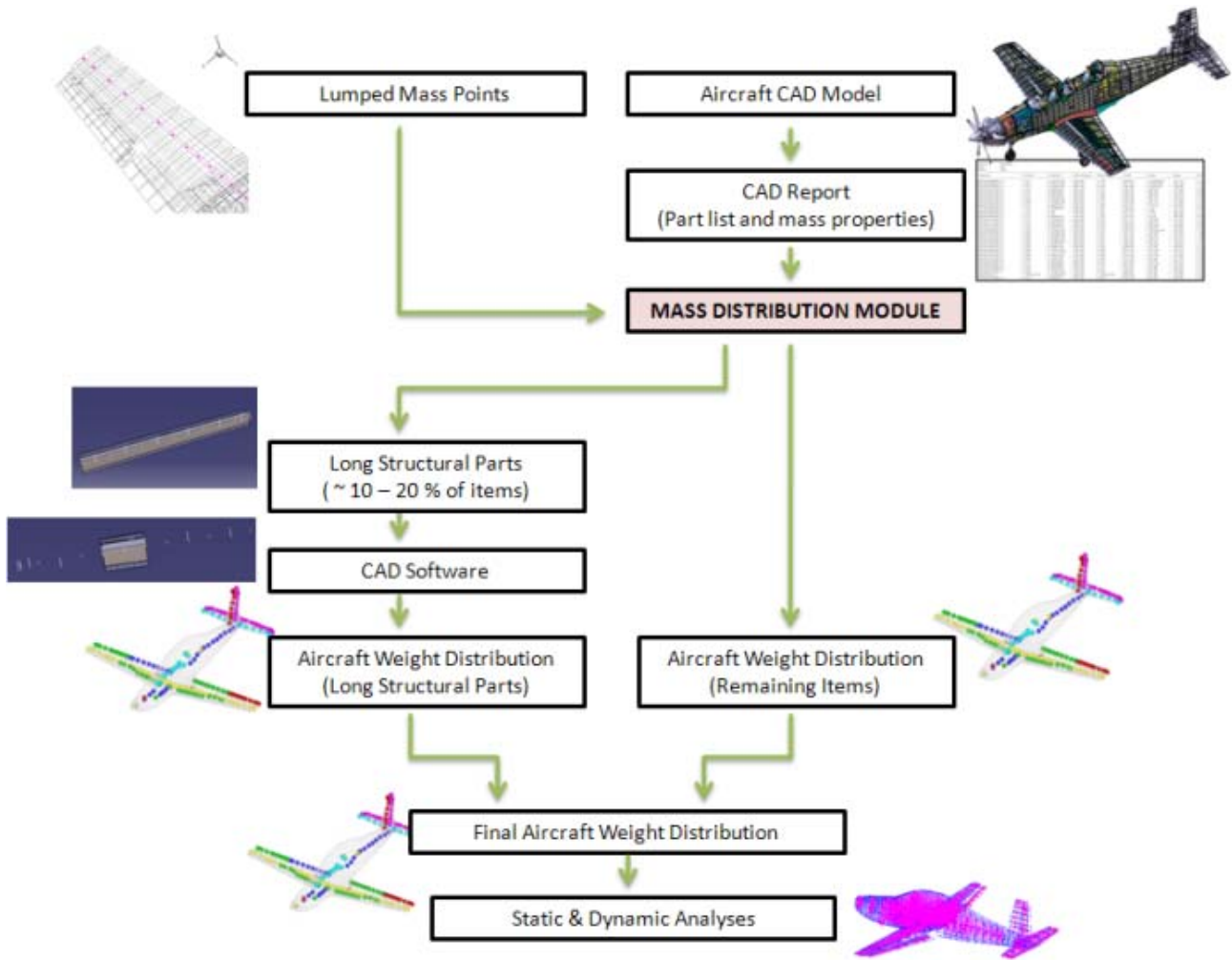


Fig. 12. The Flowchart for Hybrid Approach for Weight Distribution with Full Accuracy

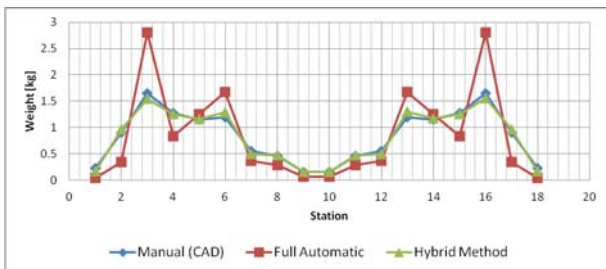


Fig. 13. Mass Distribution of a Lifting Surface: Comparison of Manual, Fully Automatic and Hybrid Methods

7 Future Works

It is planned to further automate the mass distribution calculations together with other

weight activities. The performance optimization of the developed tools is considered. Direct interaction between CAD software and our tools are being studied. Also, there are studies to remove the CAD software from the process entirely, enabling the mass distribution calculations by using only PLM reports and simple geometric data of the parts.

8 Conclusion

In this paper, the weight activities during aircraft design projects are presented. The efforts for organization and automation of the activities during aircraft detail design phase are mentioned. Among those activities, the mass distribution procedure is explained. The interaction between the aircraft mass distribution and overall design cycle is

described. The existing and new methods for calculation of aircraft mass and inertia distribution are explained in detail.

It was shown that the method developed for the mass distribution helped to increase speed, controllability and accuracy of the process. The hybrid method, which involves both automated and manual process, significantly reduces the workload, human error and time spent for the calculation of mass distribution without any loss in fidelity.

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