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Aircraft Mass Estimation Methods

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ABSTRACT

Weight minimization of an airplane design is a subject of extreme importance considering the aspect of cost estimation. While considering the design of large airplanes reduction of weight is done at some high performance designs. In various cases reduction of weight in one component leads to added weight in the other, leading to the snowball effect of the weight growth. The prospect to achieve a weight reduction and the costs depend upon the phase of the design process. The aircraft's mass is required to calculate flight performance and to assess the design. Individual masses are required to determine the centre of gravity and the positioning of the landing gear and the wings. In this paper various weight estimation techniques has been reviewed. This review does not consider getting into details of particular method, rather a brief description of various methods and interesting features have been presented here. The focus has been given on commercial transport airplane.

***Keywords* -** Aircraft design, Centre of gravity, Commercial transport, Weight minimization.

I. INTRODUCTION

Weight prediction in the preliminary sizing is essential for the performance prediction, centre of gravity determination, design of the undercarriage and providing weight limits to various departments. Good weight estimation starts with clear definitions and effective subdivision of the items. The airplane is composed of a large number of parts which can be combined into groups according to several schemes. The weight of these groups and several combinations of groups are of importance in the design. During the initial conceptual design the choice of the airplane layout, geometry and detailed configuration affects weight. The design layout should be carefully optimized and high accuracy of the initial weight prediction is a prerequisite. Weight prediction is necessary not only to make an assessment of the design qualities, but also to set a goal for the structural and systems design offices. The initial weight prediction must be a realistic challenge.

During detail design it is essential to save every small item of weight that can possibly be saved, in order to ensure a high standard of weight predication accuracy and to continuously monitor the weight, using an effective weight control system. In order to save weight, the use of advanced materials and sophisticated manufacturing techniques may be considered, resulting in a reduction of the amount of material required. The weight saving may be used to reduce the takeoff weight or to increase the payload or fuel load. However, the cost involved may lead to a noticeable increase in the price of the airplane and as assessment of the value of, the weight saving should be made. The aircraft weight is estimation is done by subdividing the parts into various groups,

***Airframe structure*:** The wing group, the tail group, the body group, the gear group and the engine nacelle group. The surface controls group may be classified as airframe structure or as a part of the airframe services.

***Propulsion group*:** The engines, items as associated with engine installation and operation, the fuel system, and thrust reversing provisions.

***Airframe equipment and services*:** APU's, the hydraulic, electric and electronic systems, furnishings and equipment, air-conditioning, anti-icing systems and other equipment. A further subdivision into fixed and removable equipment is useful for obtaining an accurate and repeatable empty weight definition.

***Fixed equipment and services*:** they are considered an integral part of a particular aircraft configuration. These include the weight of fixed ballast and the fluids which are contained in a closed system.

Removable equipment and services: are those items of equipment or system fluids that are not considered an integral part of a particular aircraft configuration. Removable separating walls, passenger seats, floor covering, basic emergency equipment.

***Operational Items*:** are those items of personnel, equipment and supplies that are necessary on a particular operation, unless already included in the basic empty weight. These items may vary for a particular airplane configuration according to the operator's allowances for the service intended. However, a minimum crew is defined for each airplane by government regulations.

Section2 describes some of the mass estimation methods. Section 3 gives a brief explanation about the methods involved in wing mass estimation. Section 4 describes the fuselage mass estimation. Section 5 deals with the tail plane mass estimation. Section 6 explains the other structural mass estimation.

I. SECTION 2

Mass Estimation Methods

Mass estimation at the conceptual design stage should be predicted appropriately in advance of detailed drawings of the parts that are being prepared. Statistical adaptation of data from the past designs is the means to predict the accurate component mass at the conceptual design phase. During the conceptual design stage, iterations are important when the configuration changes. Typically, there are three methods [5] used in evaluating mass (i.e., weight) estimations at the conceptual design stage:

Rapid Method

This method depends on the statistical average of mass one level below major aircraft components. The mass is expressed in terms of percentage (alternatively, as a fraction) of the MTOM. All items should total 100% of the MTOM; this also can be given in terms of mass per wing area (i.e., component wing-loading). This rapid method is accomplished at the price of considerable approximation. A rapid mass estimation method is used to quickly obtain the component weight of an aircraft by comparing it in terms of a fraction given in the percentage of maximum takeoff mass (Mi/MTOM), where the subscript *i* represents the ith component. A newer designs show improvements, especially because of the newer materials used.

Graphical Method

This method holds plotting of component weights of various aircraft already manufactured to fit into a regression curve. Graphs are generated from analytical considerations, superimposed by actual data. Though graphical method is the fastest method it does not provide fine resolution. Obtaining details of component mass for statistical analysis from various industries is difficult. The graphical method is based on failure analyses of an existing design. The fact of adapting all the variables affecting weight in graphical method may be hard enough, and may prove impractical because there will be separate trends based on choice of material, maneuver loads, fuselage layout, type of engine integrated, wing shape, control architecture (e.g., FBW is lighter), and so forth. The simplest form, as explained here gives a preliminary estimate of component and aircraft weight. At the conceptual design stage, when there is a stage where only technology has to e adopted and a three-view drawing are when only the technology level to be adopted and the three-view drawing are accessible to predicted weight. However, with severe analyses using semi-empirical prediction, better accuracy can be achieved.

Semi-Emphirical Method

This method is considered to be more efficient, here it uses semi-empirical relations derived from a theoretical background and evaluated by actual data that has been statically correlated. The factors in the semi-empirical method can be filtered to match the technology level and types of material used. These expressions can be represented graphically, with different graphs. When grouped together in a generalized manner, they are the graphs in the graphical method described earlier. The first two methods of component mass estimation provide a starting point for the design progression. The advent of solid modeling (i.e., CAD) of components improved the accuracy of the mass prediction methodology; with CAD, weight change due to a change in material can be easily captured. As soon as the component drawing is completed, the results are on the spot and carry on through subassembly to final assembly. CAD modeling of parts occurs after the conceptual design phase has been completed. The design drivers for civil aircraft have always been safety and economy. Civil aircraft design developed in the wake of military aircraft evolution.

Following are general comments relative to civil aircraft mass estimation: For a single engine, propeller-driven aircraft, the fuselage starts aft of the engine bulkhead because the engine nacelle is accounted for separately. These are mostly small aircraft; this is not the case for wing-mounted nacelles

2. The fixed-undercarriage mass fraction is lower than the retractable type. The extent depends on the retraction type (typically 10% higher).

3. Neither three-engine aircraft nor fuselage-mounted, turboprop-powered aircraft are discussed in this book. Not many of these types of aircraft are manufactured. Sufficient information has been provided herein for readers to adjust mass accordingly for these aircraft classes.

This method is derived from theoretical formulation and then filtered with statistical data to evaluate aircraft component mass. Various forms of semi-empirical weight-prediction formulae have been formulated by various scientists and analysts. Although every proposal had similarities in the basic content, still they could differ by 25%. The best way is to tune first and then use it for novel design i.e. to know the mass data of the aircraft and then modify the semi-empirical relation. To explain the impact of the related parameters on mass, their influence is shown by increase in mass and decrease in magnitude of the driver. This evaluation is followed by semi-empirical relations to fit statistical data as high as possible. When the component masses are more accurately evaluated, the MTOW is to demonstrate the effect of the related drivers on mass, their influence is modified to the enhanced accuracy.

Importance of Light Weight

During the initial conceptual design the choice of the airplane layout, geometry and detailed configuration affects weight. The design layout should be carefully optimized and high accuracy of the initial weight prediction is a prerequisite. Weight prediction is necessary not only to make an assessment of the design qualities, but also to set a goal for the structural and systems design offices. The initial weight prediction must be a realistic challenge to both. This design type of work, being the normal task of the preliminary design office, involves virtually no extra costs.

During detail design it is essential to save every small item of weight that can possibly be saved, in order to ensure a high standard of weight predication accuracy and to continuously monitor the weight, using an effective weight control system. In most airplane development programs weight reduction programs must be started occasionally in order to redress unfavorable weight creep which may have become apparent. Some cost may be involved in the form of additional manpower, but this is often a small portion of the penalties incurred by overweight design.

In order to save weight, the use of advanced materials and sophisticated manufacturing techniques may be considered, resulting in a reduction of the amount of material required. The weight saving may be used to reduce the takeoff weight or to increase the payload or fuel load. However, the cost involved may lead to a noticeable increase in the price of the airplane and as assessment of the value of, the weight saving should be made.

In comparing the structure weight fraction of modern airplane types with old one, it is sometimes noted that this fraction has not improved, probably for the following reasons:

The relative fuel and propulsion group weights must be taken into account. Due to the improved engines of recent years, these weight fractions have decreased and, for the same payload the structure weight fraction tends to increase.

The wings [4] of modern high-subsonic airplanes are swept and relatively thin. More emphasis has to be laid on stiffness requirements, leading to weight penalties.

Improved high-lift devices have resulted in higher unit structure weights for the wings.

Fatigue life requirements are critical for modern transport airplanes, leading to limitations in the stress levels.

More stringent airworthiness requirements concerned with the safety and comfort level have resulted in more complex and heavier structure and airframe systems.

Weight prediction in the preliminary design is necessary to performance prediction, centre of gravity determination and design of the undercarriage, and also to provide the various design departments with realistic design weights and weight limits. Good weight estimation starts with clear definitions and effective subdivision of the items. The airplane is composed of a large number of parts which can be combined into groups according to several schemes. The weight of these groups and several combinations of groups are of importance in design

II. SECTION 3

Wing Mass Estimation

Torenbeek Method

Torenbeek[8] has discussed the sensitivity of airplane performance and operating economy to the empty weight. An accurate weight prediction in the preliminary design stage is a most effective way to control the weight; it begins with a consistent scheme for weight subdivision and limitations. Considerations are presented for making a sound choice of the operational weight limitations. Some general remarks on weight prediction methods are followed by a comprehensive collection of available and consistent methods, useful for most categories of modern civil aircraft. Attention has been paid both to simple approximate methods and to more detailed procedures, for which detailed design information must be available.

An accurate wing weight estimate can be made in preliminary design as the loads on the wing are known well at the design stage. Usually the bending moment in flight is assumed to be decisive for most of the primary structure. For a certain category of high-speed aircraft, torsion stiffness requirements can be considered main and the extra structure weight required safeguarding against flutter may amount to as much as 20% of the wing weight. A large portion is also made up of secondary structure and non-optimum penalties such as joints, non-tapered skin, and undercarriage attachments.

The following expression is valid for the case of a wing-mounted retractable undercarriage, but not for wing mounted engines.

$$\frac{W_w}{W_G} = K_w b_s^{0.75} \left\{1 + \sqrt{\frac{b_{ref}}{b_s}}\right\} n_{ult}^{0.55} \left(\frac{\frac{b_s}{t_r}}{\frac{W_g}{S}}\right)^{0.30}$$

The weight includes high lift devices and ailerons. Wing optimization studies must be sensitive to variations in the external geometry, and configuration characteristics. It is generally recognized that for modern wing designs the weight of high-lift devices should be determined separately. The structural weight fraction, for a given cantilever ratio and wing loading increases with the wing span. This is associated with the square-cube law can be counteracted by increasing the wing loading. This is one of the reasons why large aircraft usually have high wing loadings. Decreasing the cantilever ratio is unfavorable as it results in a drag increment; its value is sustainable between 35 and 45.

LTH (Luftfahrt Technischen Handbuch) – MA401 Method

The LTH serves to standardize and rationalize engineering work in all phases of material development and in-service use of aerial vehicles and flight equipment. It provides support in the fulfillment of company, customer and governmental authority's quality standards and the improvement of German industry competitiveness in international joint projects. It supports engineers in solving specific problems and is also intended to assist young aviation engineers.

MA401 method was formulated to compute the manufacturers mass empty (MME) respectively the operators mass empty (OME) of a large civil jet transport aircraft. In this paper, 'large' aircraft are aircraft having a maximum take of mass (MTOM) of more than 40t respectively having 70 or more passenger seats in a typical layout.

The wing mass estimation includes the overall wing structure from tip to tip including centre wing box, broken down as follows:

1. skins (including stringers)
2. spars
3. Ribs
4. Pylon attachments (front and rear attachment, fairing attachments, spigot attachment)
5. Landing gear support (gear beam and ribs, attachments and fittings)
6. Fixed leading edge (ribs, panels, movable support structures)
7. Movable leading edge (slat, droop nose, Krueger flaps, slat tracks)
8. fixed trailing edges (panels, false work, flap tracks and attachments, spoiler and aileron support)
9. Movable trailing edges (flaps including flap track rear link and carriages, ailerons and spoiler)
10. Miscellaneous (external paint final coat, wing tips, winglets, sealant, fairings, fittings and supports)

The wing mass excludes systems (e.g. actuators) but fittings on which e.g. the actuators fixed are included into wing mass but not the bolts, that are used for fixing the actuator.

$$m_{wing} = 2.20013 * 10^{-4} * \left[401.146 * A_{wing}^{1.31} + MTOM^{1.1038}\right] * \left(\frac{T}{C_{rep}}\right)^{-0.5} * AR^{1.5} * \frac{1}{cos\emptyset_{25}}$$

m_{wing}	4100-50300	Kg
A_{wing}	75-550	m^2
MTOM	40000-400000	Kg
T/C_{rep}	0.10-0.15	-
AR	6.9-9.6	-
φ_{25}	15.0-37.5	[◦]

Value of the parameters that may vary in the wing mass equation

Raymer Method

The weight estimation of a conceptual aircraft design is a critical process. The weight engineers have an alignment with others, serves as a referee during the design project. There are various levels in weight analysis. Crude statistical techniques are used in estimating the empty weight for a given take-off weight.

Raymer weight analysis starts with a crude component build up based on the plan form areas, wetted areas and percents of gross weight.

$$W_{wing} = 0.036 * S_w^{0.758} W_{fw}^{0.0035} \left(\frac{A}{\cos^2\Lambda}\right)^{0.6} * q^{0.006} \lambda^{0.004} \left(\frac{100\frac{t}{c}}{cos\Lambda}\right)^{-0.3} * \left(N_z W_{dg}\right)^{0.49}$$

III. SECTION 4

Fuselage Mass Estimation

Torenbeek Method

The fuselage makes a large contribution to the structural weight, but it is much more difficult to predict by a common method than the wing weight. The reason is the large number of local weight penalties in the form f floors, cutouts, attachment and support structure, bulkheads, doors, wingows and other special structural features.

Fuselage weight is affected primarily by the gross shell area, defined as the area of the entire outer surface of the fuselage. The following simple weight estimation method for Al-alloy fuselages is slightly updated and modified for modern types. The basic fuselage weight is

$$W_f = k_{wf} \sqrt{V_D * \frac{l_t}{b_f + h_f}} * S_G^{1.2}$$

In this equation 8% should be added for pressurized cabins, 7% if main landing gear is attached to the fuselage, and an extra 10% for freighter aircraft. If there is no attachment structure for the landing gear nor a wheelbay, 4% may be subtracted from the basic weight.

LTH (Luftfahrt Technischen Handbuch) – MA401 Method

The fuselage mass includes the complete fuselage structure, broken down as follows

1. panels (skin shell panels, stringer, doublers, window frames)
2. frames (frames, pressure bulkheads, clips, frame junction fittings)
3. doors (doors, locking mechanism, hinge arm and fittings, door seal)
4. Windscreens and windows
5. Windscreen and opening frames
6. Cabin floor structure
7. Cargo compartment floor structure
8. special structures (landing gear bays, keel beam, VTP and HTP attachment, APU attachment)
9. Fillet and fairings (belly fairing, leading edge root fillets, upper/lower wing fairing, APU fairing)
10. Miscellaneous (external paint final coat, stairs, barrier wall, installation parts)

The fuselage mass excludes systems (e.g. actuators) but fittings on which e.g. the actuators are fixed and are included into wing mass but not the bolts, that are used for fixing the actuator.

$$m_{fus} = 12.7 * \left(l_{fus} * d_{fus}\right)^{1.2982} * \left(1 - \left[-0.008 * \left(\frac{l_{fus}}{d_{fus}}\right)^2 + 0.1664 * \left(\frac{l_{fus}}{d_{fus}}\right) - 0.8501\right]\right) * \frac{\max(h_{fus}, w_{fus})}{d_{fus}}$$

m_{fus}	1700-38000	Kg
l_{fus}	19-74	Metre
h_{fus}	3.3-6.8	Metre
w_{fus}	3.3-6.5	Metre
d_{fus}	3.3-6.65	Metre

Value of parameters that may vary in the fuselage mass equation

Raymer Method

The fuselage of the airplane is considered to be main part of an aircraft body and is considered to be hollow tube holding all pieces of the plane together. Hollow configuration helps in weight reduction. Usually fuselage shape is decided according to the mission to be pursued. The following equation has been given by Raymer for fuselage weight estimation.

$$W_{fuselage} = 0.052 * S_f^{1.086} \left(N_z * W_{dg}\right)^{0.177} * L_t^{-0.051} \left(\frac{L}{D}\right)^{-0.072} * q^{0.241} + W_{press}$$

Tail Plane Mass Estimation

IV. SECTION 5

Torenbeek Method

This weight accounts for only a small part of the MTOW but on account of its remote location it has an appreciable effect on the position of the airplane's center of gravity. Accurate weight prediction is diifficult due to the wide variety of tailplane configurations and the limited knowledge of strength, stiffness and other conditions which will govern the design. For relatively low-speed light aircraft, the maneuvering loads are most important and the specific tailplane weight is affected by the load factor. In transport aircraft and executive jets the design dive speed appears to have a dominant effect.

The following equation is used in estimating the horizontal tail mass estimation.

$$\frac{W_h}{S_h} = k_h * f(S_h^2 * \frac{V_D}{\sqrt{cos\wedge_h}})$$

The following equation is used in estimating the vertical tail mass estimation.

$$\frac{W_v}{S_v} = k_v * f(S_v^2 * \frac{V_D}{\sqrt{cos\wedge_v}}$$

LTH (Luftfahrt Technischen Handbuch) – MA401 Method

The HTP mass includes the complete HTP structure from tip to tip, broken down as follows:

1. Torsion box (skins, spars, ribs, sealants, fuselage attachment)
2. Leading edge (skins, ribs, panes)
3. fixed trailing edge (panels, ribs, and hinge and actuator fittings)
4. Elevators (complete elevator body, hinge and actuator fittings)
5. Tips and fairings (tips, fairing supports and fairings)
6. Miscellaneous (external paint final coat, HTP-fuselage bolts, torsion box-leading edge and torsion box-trailing edge bolts)

The HTP mass excludes systems (e.g. actuators) but fittings on which e.g. the actuators are fixed are included into wing mass but not the bolts that are used for fixing the actuator.

$$m_{htp} = 12.908 * A_{htp}^{1.1868} * (1 + \frac{0.1 - \frac{T}{C_{rep}}}{\frac{T}{C_{rep}}})$$

m_{htp}	400-4000	Kg
A_{htp}	20-140	m^2
T/C_{rep}	0.088-0.11	-

Value of parameters that may vary in the HTP mass equation

The VTP mass includes the complete VTP structure, broken down as follows:

1. torsion box (skins, spars, ribs, sealants, fuselage attachment)
2. leading edge (dorsal fin, skins, ribs, panes)
3. fixed trailing edge (panels, ribs, hinge and actuator fittings)
4. rudders (complete rudder body, hinge and actuator fittings)
5. tips and fairings (tips, fairing supports and fairings)
6. miscellaneous (external paint final coat, VTP-fuselage bolts, torsion box-leading edge and torsion box-trailing edge bolts)

The VTP mass excludes systems (e.g. actuators) but fittings on which e.g. the actuators are fixed are included into wing mass but not the bolts that are used for fixing the actuator.

$$m_{VTP} = 25.056 A_{VTP}^{1.0033}$$

m_{vtp}	300-1800	Kg
A_{vtp}	12-78	m^2

Value of parameters that may vary in the VTP mass equation

Raymer Method

A tail plane is a small surface that ensures lift and is located on the tail behind the main lifting surface of a fixed wing aircraft. There are basically two tail planes of great importance, horizontal and vertical tail plane [2]. As per the fact it is not necessary that tail plane should be located in all fixed wing as canards can be replaced by their usage. Mainly the tail plane serves three basic purposes equilibrium, control and stability. The following equation has been given by Raymer for Tail plane mass estimation.

$$W_{horizontal\ \ tail} = 0.016(N_z W_{dg})^{0.414} * q^{0.168} * S_{ht}^{0.896} \left(\frac{100\frac{t}{c}}{cos\wedge}\right)^{-0.12}$$

$$W_{vertical\ \ tail} = 0.073\left(1+0.2\frac{H_t}{H_v}\right)\left(N_z W_{dg}\right)^{0.376} * q^{0.122} * S_{vt}^{0.873}\left(\frac{100\frac{t}{c}}{cos\ \Lambda_{vt}}\right)^{-0.49} * \left(\frac{A}{COS^{\wedge}2\ \Lambda_{vt}}\right)^{0.357} * \lambda_{vt}^{0.039}$$

V. SECTION 6

Other Structural Mass Estimation

Landing Gear Group

Torenbeek Method

The undercarriage has a well defined set of loading conditions and weight prediction can therefore be dealt with on a analytical basis. To this end the weight of each gear must be subdivided into

1. Wheels, brakes, tires, tubes and air
2. Main structure i.e. legs and struts
3. Items such as the retraction mechanism, dampers , controls, etc.

The first part of the weight prediction process is to decide upon tire and wheel size, inflation pressure, location of the gears, length of the legs. The weight of conventional undercarriages may be found by summation of the man gear and the nose gear, each predicted with separately with the following expression.

$$W_{uc} = k_{uc}\left\{A + B * W_{to}^{\frac{3}{4}} + C * W_{to} + D * W_{to}^{\frac{3}{2}}\right\}$$

In large airplanes a large part of the gear structure can be highly stressed, while the use of higher inflation pressures on large aircraft saves some weight as well. For main landing gears the weight fraction does not appreciably decreases at takeoff weights above 45,000 Kg, but for nose gears there is still a reduction of the weight fraction up to very large airplane sizes. There is a possibility that in many aircraft the critical load is formed by the landing impact load and that the MLW should therefore be used to predict the undercarriage weight. A reasonable approximation for the weight of retractable undercarriage is 4.7% of the MLW.

LTH (Luftfahrt Technischen Handbuch) – MA401 Method

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Raymer Method

The landing gear is the main component of an aircraft which helps in supporting the entire weight of the aircraft, especially during landing and ground operations. The following equations have been formulated by Raymer for Landing gear weight estimation.

$$W_{main\ \ landing\ \ gear} = 0.095 * (N_l W_l)^{0.768} * \left(\frac{L_m}{12}\right)^{0.409}$$

Engine section or Nacelle Group

Torenbeek Method

These values include the pylon weight and extended nacelle structure for a thrust reverser installation. In the absence of thrust reversing a reduction of 10% may be assumed. In a more detailed weight analysis taking into account the configuration and geometry of the nacelle and engine mounting is desirable, some degree of structural design must be attempted first. The weight penalty due to noise suppression material obviously depends upon the amount of suppression desired; the engine manufacturer should be consulted for detailed data. A typical weight penalty is 20% of the nacelle weight, apart from the extra weight of the engine itself.

For a light aircraft, single tractor propeller in the fuselage nose:

$$W_n = 1.134\sqrt{P_{to}}$$

This weight refers to the complete engine section in front of the firewall. Multi-engine aircraft, reciprocating engines,

Horizontally opposed cylinders - $W_n = 0.145 P_{to}$

Other engine types – $W_n = 0.0204 P_{to}^{\frac{5}{4}}$

LTH (Luftfahrt Technischen Handbuch) – MA401 Method

The power unit mass includes: engines, nacelles, all systems included in the removable power plant, and residual fluids hydraulic, trapped fuel and oil in lines (not oil in tanks). Also included are aircraft systems associated with engines: engine controls, bleed air and fuel systems. In detail it is broken down as follows:

- equipped engines (complete removable power plant; w/o engine tank oil and electrical generators oil)
- basic engine in manufacturer delivery configuration
- nacelle structure (inlet cowls, fan cowls, nozzles, center body, reversers and engine mounts, external paint final coat)
- nacelle systems (all systems located within the nacelle)
- bleed air system (in pylons, wing and fuselage)
- engine control system (in pylons, wing and fuselage)
- fuel system (incl. pipes, couplings, removable brackets, control and monitoring equipment, semi equipment and their installations; excl. cables, electrical control and monitoring items)
- inert gas system (incl. inert gas generation, storage, distribution, generation control and generation indicating systems)

The system masses exclude fittings on which they are fixed but include the bolds that are used for fixing the systems.

$$m_{PPT} = n_{PPT} * 0.2953 * SLST^{0.8063}$$

m_{PPT}	4300-28000	Kg
n_{PPT}	2;4	-
SLST	61000-520000	N

Value of Parameters that may vary in the Power Plant mass equation

Raymer Method

Fuel system helps the crew to pump, manage and deliver fuel to the propulsion system of an aircraft. The purpose varies according to the type of aircraft they are installed at. The following equation [1] has been devised by Raymer for fuel system weight estimation.

$$W_{fuel\ system} = 2.49 V_t^{0.726} * \left(\frac{1}{1+\frac{Vi}{Vt}}\right)^{0.363} * N_t^{0.242} * N_{en}^{0.157}$$

Roskam Method

The mass estimation method [9] was formulated as Class1 and Class2 by Jan Roskam. Class1 method is centered towards estimation of the airplane Gross weight and percentages of important Airplane components. These percentages are multiplied by the take-off weight to obtain a first estimate of the weight of each major component. Class2 **(Roskam 1989)** methods are more centered to weight equations of different aircraft components. These equations are based on statistics. To utilize the method V-N diagram and preliminary structural arrangement is very essential.

The following method where mass breakdown of different aircraft components are focused is a class 1 as explained by Roskam. The following are the steps to be carried on for mass estimation.

Operating empty mass m_{OE} has to be calculated using the following equation,

$$\frac{m_{OE}}{m_{MTO}} = 0.23 + 1.04 * \frac{T_{to}}{m_{MTO} * g}$$

Where $\frac{T_{to}}{m_{MTO} * g} = 0.3$

The following equation can be used to find the Maximum Take off Mass.

$$m_{MTO} = \frac{m_{PL}}{1 - \frac{m_F}{m_{MTO}} - \frac{m_{OE}}{m_{MTO}}}$$

And $\frac{m_F}{m_{MTO}} = 1 - M_{ff}$,

Where $M_{ff} = \frac{m_{SO}}{m_T} * \frac{m_T}{m_L} * \frac{m_L}{m_{DE}} * \frac{m_{DES}}{m_{CR,ALT}} * \frac{m_{CR,ALT}}{m_{CLB}} * \frac{m_{MA}}{m_{DES}} * \frac{m_{DES}}{m_{LOI}} * \frac{m_{LOI}}{m_{CR}} * \frac{m_{CR}}{m_{CLB}} * \frac{m_{CLB}}{m_{TO}} = \frac{m_{SO}}{m_{TO}}$

Where the mass fractions according to Roskam are as follows,

TYPE OF AIRCRAFT	ENGINE START	TAXI	TAKE-OFF	CLIMB	DESCENT	LANDING
Business jet	0.99	0.995	0.995	0.98	0.99	0.992
Jet transport	0.99	0.99	0.995	0.98	0.99	0.992
Fighter	0.99	0.99	0.99	0.96-0.9	0.99	0.995
Supersonic cruise	0.99	0.995	0.995	0.92-0.87	0.985	0.992

VI. CONCLUSION

This paper gives a broad idea about the techniques used for estimating different aircraft components. This paper can be used while estimating or analyzing aircraft component weight mathematically. Further simulations can also be done depending on the aircraft model chosen. Basic idea behind this paper is to provide a clear idea about the techniques that has been used in Mass estimation of different aircraft components.

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REFERENCES

[1] Eurico2000,"Vergleich Verschiedener Verfahren zur Masseprognose von Flugzeugbaugruppen im frühen Flugzeugentwurf - Flügel, Leitwerk, Einsatzausrüstung - HAW Hamburg, theoretische Arbeit, 2000

[2]Eurico," Vergleich verschiedener Verfahren zur Masseprognose, Flugzeugbaugruppen im frühen Flugzeugentwurf", HAW Hamburg, theoretische Arbeit, 2000

[3]Simona,"Mach number, relative thickness, sweep and lift coefficient of the Wing - An empirical investigation of parameters and equations, HAW Hamburg, Aufgabenstellung zum Projekt gemäß Prüfungsordnung",2005.

[4] Mark D. Ardema, Mark C. Chambers, Anthony P. Patron, Andrew S. Hahn, Hirokazu Miura, and Mark D. Moore,"Analytical Fuselage and Wing Weight Estimation of Transport aircraft, NASA Technical Memorandum 110392.

[5] Ajoy Kumar Kundu, "Aircraft Design", Published in the United States of America by Cambridge University Press, New York ISBN-13 978-0-521-88516-4, 2010

[6] André Freitag, "Fachbereich Fahrzeugtechnik und Flugzeugbau Statistik zu einer Class1 Masseprognose", HAW- Hamburg, 2006

[7]CERAS, URL:http://ceras.ilr.rwthaachen.de/trac/wiki/CeRAS/AircraftDesigns/CSR01/Mass%20Breakdown

[8]Egbert Torenbeek," Synthesis of Subsonic airplane", Delft University Press, Kluwer academic publishers. ISBN: 9029825057, 1976.

[9]Jan Roskam," Component Weight Estimation", Band-5, 1989.