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Aircraft Design and Weight Estimation Nomenclature

By Jahnavi & Avinash

Abstract- Weight components of airplane explained as follows:

a) Crew weight (W_c)

The crew comprises the people necessary to operate the airplane in flight. e.g., Pilot, Co-pilot, Airhostess etc.

b) Payload weight (W_p)

The payload is what the airplane is mentioned to transport passengers, baggage, freight etc. (Military use the payload includes bombs, rockets and other disposable ordnance) .

c) Fuel weight (W_f)

This is the weight of the fuel in the fuel tanks. Since fuel is consumed during the course of flight. is a variable, decreasing with time during the flight.

d) Empty weight (W_e)

This is weight of everything else-the structure engines (with all accessory equipment), electronic equipment landing gear, fixed equipment and anything else that is not crew, payload or fuel.

e) Gross weight (W_0)

The sum of these weights is the total weight of the airplane. Gross weight or total weight varies through the flight because fuel is being consumed. The design take off gross weight is the weight of the airplane at the instant it begins its mission. It includes the weight of the fuel.

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AIRCRAFTDESIGNANDWEIGHTESTIMATIONNOMENCLATURE

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$$W_0 = W_c + W_p + W_f + W_e$$

$$W_0 = W_c + W_p + \frac{W_f}{W_0} W_0 + \frac{W_e}{W_0} W$$

$$W_0 = \frac{(W_c + W_p)}{\left(1 - \frac{W_f}{W_0} - \frac{W_e}{W_0}\right)} \quad (1)$$

i. *Estimation of empty weight fraction* (W_e/W_0)

The empty weight fraction (W_e/W_0) can be estimated from data based on

- Historical data and tables
- Refined sizing data and tables

ii. *Estimation of fuel fraction* (W_f/W_0)

The aircrafts fuel supply is available for performing the mission. The other fuel includes reserve fuel, trapped fuel (which is the fuel which cannot be pumped out of the tanks).

Fuel fraction (W_f/W_0) is approximately independently of aircraft weight. Fuel fraction will be estimated based on the mission to be flown.

I. Introduction

a) Mission profiles

Typical mission profiles for various types of aircraft are shown in Fig1. The simple cruise mission is used for many transport and general aviation designs, including home built. Following are the briefly explained the terms that are used in mission profiles:

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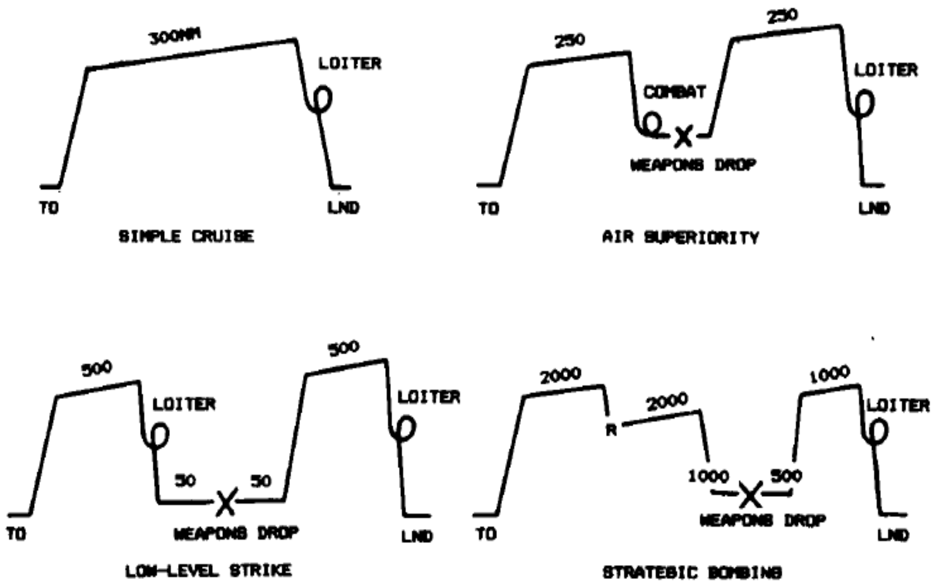

Fig.1 : Typeical mission profiles for sizing

- *Warm Up and Take-Off*

Warm Up is the engine start up for the airplane kept idling for some time to warm up. Take Off is the point where aircraft is made lift off from ground. It is the motion after warm up i.e., moving of airplane after starting and till it lifts off from the ground.

- *Climb*

It is between take-off (TO) and cruise (stead level flight with constant speed) Increase in height until airplane achieves steady level flight.

Cruise

It is the steady level flight to cover the mission distance. The mission distance is called Range.

- *Loiter*

Represent the airplane spending in air for some fixed number of minutes near airport before getting the clearance from airport signal or simple spending some time to collect data of some mission (Terrain data).

- *Dash*

It is the mission that must be flown at just a few hundred numbers of feet of the ground for low level strike.

- *Landing*

It is the aircraft landing on the runway till stopping of engine.

b) Estimation of mission segment weight fractions

The various mission segments (legs) are numbered starting from zero denoting, the start of the mission. Mission leg one is usually engine warm up and take-off. The remaining legs are sequentially numbered. For example in the simple cruise mission the legs could be numbered as (0) warm-up and take-off, (1) climb (2) cruise (3) loiter and (4) landing.

Similarly, the aircraft weight at end of each mission is denoted by W_i . Denoting "i"-th segment as mission segment weight

W_0 =Beginning airplane weight ("Take –off gross weight")

W_1 =Weight of the airplane at end of warm-up and take-off.

W_2 =Weight of the airplane at end of climb.

W_3 =Weight of the airplane at end of cruise.

W_4 =Weight of the airplane at end of loiter.

W_5 =Weight of the airplane at end of landing.

$$W_x/W_0 = \frac{W_5}{W_0} = \frac{W_1}{W_0}\frac{W_2}{W_1}\frac{W_3}{W_2}\frac{W_4}{W_3}\cdots\frac{W_5}{W_4}$$

So in general it can be written as

$$W_x/W_0 = \frac{W_i}{W_0} = \frac{W_1}{W_0}\frac{W_2}{W_1}\frac{W_3}{W_2}\frac{W_4}{W_3}\cdots\frac{W_i}{W_{i-1}}$$

Warm-up/take-off, climb and landing weight fractions:

The warm-up, take-off and landing weight fractions can be estimated historically from Table 2.

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Table 2 : Historical mission segment weight fractions

	(W_i/W_{i-1})
Warmup and takeoff	0.970
Climb	0.985
Landing	0.995

Specific fuel consumption (C)

It is the rate of fuel consumption divided by the resulting thrust. Typical values are depicted in Table3 and Table4 for jet and propeller aircrafts respectively. If the aircraft is propeller, then C should be replaced by

$$C = C_{bhp} V/(550\eta_p)$$

Table 3 : Specific fuel consumption (C)

Typical jet SFC's	Cruise	Loiter
Pure turbojet	0.9	0.8
Low-bypass turbofan	0.8	0.7
High-bypass turbofan	0.5	0.4

Table 4 : Propeller specific fuel consumption (C_{bhp})

Propeller: $C = C_{bhp} V/(550\eta_p)$ Typical C_{bhp} and η_p	Cruise	Loiter
Piston-prop (fixed pitch)	0.4/0.8	0.5/0.7
Piston-prop (variable pitch)	0.4/0.8	0.5/0.8
Turboprop	0.5/0.8	0.6/0.8

Cruise segment weight fraction

Weight fraction for cruise segment is found using Breguet range formula

$$R = \frac{V}{C}\frac{L}{D}\ln\left(\frac{W_{i-1}}{W_i}\right)$$ R = range, C = specific fuel consumption

$$\frac{W_i}{W_{i-1}} = \exp\left(\frac{-RC}{V\left(L/D\right)}\right)$$ V = velocity, L/D = lift to drag ratio

Loiter segment weight fraction

Weight fraction for loiter segment is found using Endurance formula.

$$E = \frac{L/D}{C}\ln\left(\frac{W_{i-1}}{W_i}\right)$$ E = endurance or loiter time, C = specific fuel consumption

$$\frac{W_i}{W_{i-1}} = \exp\left(\frac{-EC}{(L/D)}\right)$$ V = velocity, L/D = lift to drag ratio

The most efficient cruise is velocity for propeller aircraft occurs at velocity yielding max L/D, where as for the most efficient cruise for a jet aircraft occurs at slightly at a higher velocity yielding an L/D of 86.6% of the maximum L/D

Type of aircraft	Cruise	Loiter
jet	0.866 (L/D)max	L/D max
propeller	L/D max	0.866 (L/D) max

For any mission segment "i" the mission segment weight fraction is expressed as W_i/W_{i-1} . W_x (Assuming "x" segments are present for total mission profile) is the aircraft weight at end of the mission. W_x/W_0 ratio can be used to calculate fuel fraction.

$$W_f/W_0 = 1-(W_x/W_0)$$

At the end of the mission, the fuel tanks are not completed empty, typically a 6% allowance is made for reserve and trapped fuel

$$W_f/W_0 = 1.06[1-(W_x/W_0)]$$

c) Estimate of gross weight at take-off (W_0)

W_e/W_0 is function of W_0, W_f/W_0 is also a function of W_0 . W_0 is calculated from equation(1) through process of iteration. W_0 is taken a guess value and, then RHS value of equation(1) is calculated which should match the value of assumed, if it doesn't, increment the assume by some value and iterate it. This process is continued till the absolute difference of RHS value and assumed value is the least and that iteration step will be your nearest solution.

II. Aircraft Conceptual Sketch and Its Gross Weight Estimation Algorithm Aim

Write the request for proposal for the particular aircraft, draw the conceptual sketch of the aircraft for given type of aircraft, draw the mission profile and write generic algorithm for gross take-off weight estimation

Theory

a) Conceptual Design

Conceptual design begins with a specific set of design requirements established from customer or a

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company-generated guess what future customers may need.

Design requirements include

- Aircraft range
- Payload
- Take-off distance
- Landing distance
- Maneuverability and speed requirements

Design begins with innovative idea rather than as a response to a given requirement. Before design a decision is made to what technologies to incorporate, it must use only currently available technologies as well as existing engines and avionics. If designed to build in more distant future, then an estimate technological state of the art must be made to determine which emerging technologies will be ready for use at that time.

Design begins drawing with a conceptual sketch like shown in Fig1. Good conceptual sketches start with approximate sketch of following:

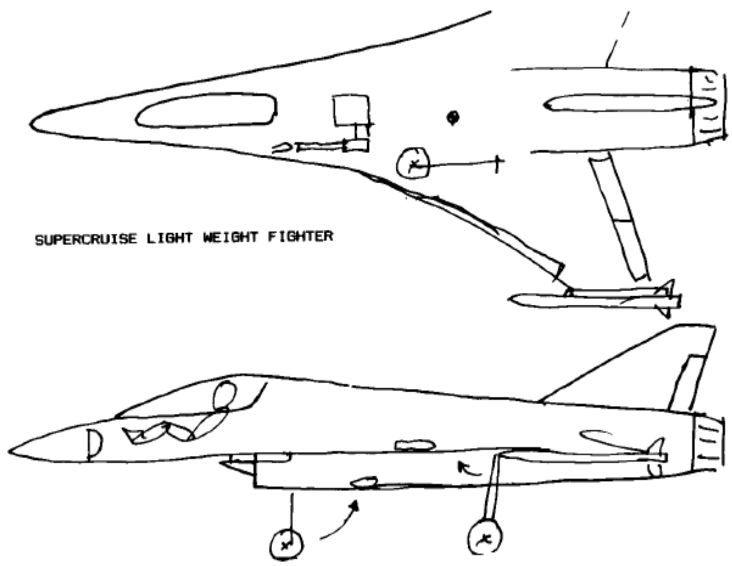

Fig.1 : Initial sketch

1) Wing
2) Tail geometries
3) The fuselage shape
4) The internal locations of the major components such as the:
   a) Engine
   b) Cockpit
   c) Payload/passenger compartment
   d) Landing gear
   e) Fuel tanks.

III. Sizing

The conceptual sketch is used to estimate aerodynamics and weight fractions by comparisons to previous designs. These estimates are used to make a first estimate of the required total weight and fuel weight to perform the design mission.

First order sizing provides the information to needed to develop an initial design layout in three view format. This three view drawing is completed with the internal arrangement in detail. The initial layout is analyzed to determine if it will perform the mission as indicated by the first-order sizing.

IV. Algorithm for Gross Take-off Weight Estimation

Following steps are involved in gross take-off weight estimation:

- Study the design objectives.
- Sizing mission starts here.
- Aspect ratio selection is done here.
- Sketch the layout in three views.
- Select L/D ratio and engine specific fuel consumption.
- Estimate fuel weight fraction.
- Select empty weight fraction (Historical trends).
- Guess initial gross weight.
- Calculate gross weight from equation.
- Iterate for gross weight by going to step8, until guess and calculated are matched.

The following flow chart explains the same algorithm as explained previous

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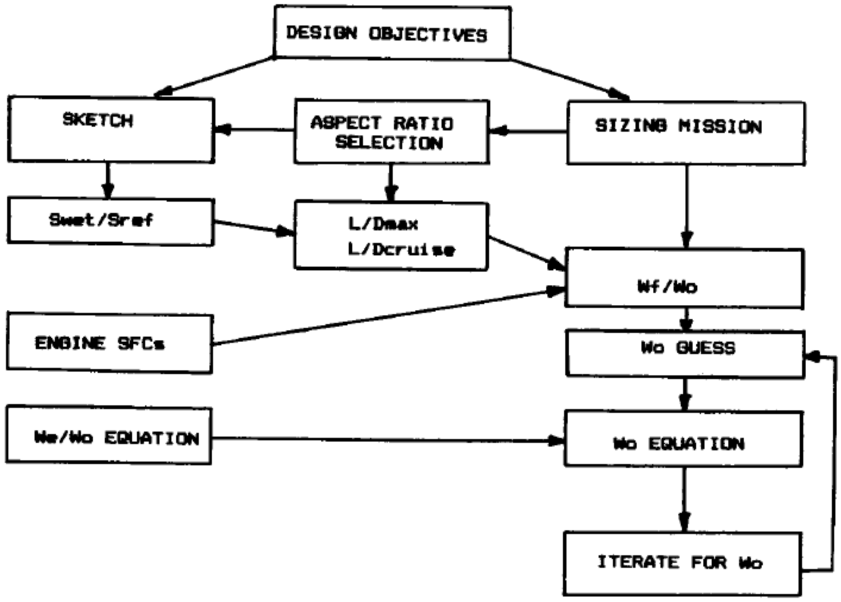

V. Procedure

- Write the request for proposal for the given aircraft. It should be in the form of parameters and requirements for the aircraft.
- Draw the conceptual sketch of the aircraft as explained in theory.
- Draw the mission profile for the aircraft.
- What do you understand by flight vehicle design? Explain it with various examples.
- What do you understand by weight estimation and write the algorithm for gross take-off weight estimation.

VI. Result

The take-off weight can be estimated by doing the iterations, until we get,
W_0 guess = W_0 Calculated

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