3.3 Empty Weight Estimation

Raymer (along with many other textbooks on aircraft sizing) shows the empty weight fraction (W_e/W_0) as an exponential function of W_0. This relationship can be expressed more simply as a linear relationship without a significant loss of accuracy. In this most simple form, there are some parts of W_e that are proportional to W_0 and some that aren't, or

$$W_e = K + GW_0 \qquad (3.3.1)$$

where K represents weight that is not proportional to W_0 (such as the cockpit or flight deck and avionics), and GW_0 represents everything else. We can compare these two methods using a spreadsheet. Take the equation in Table 3.1 and convert it to the form

$$W_e = AW_0^{(C+1)}K_{vs} \qquad (3.3.2)$$

where the constants are defined in the textbook. If you plot these in a spreadsheet you will get a pair of curves looking something like Fig. 3.3.1 for jet transports.

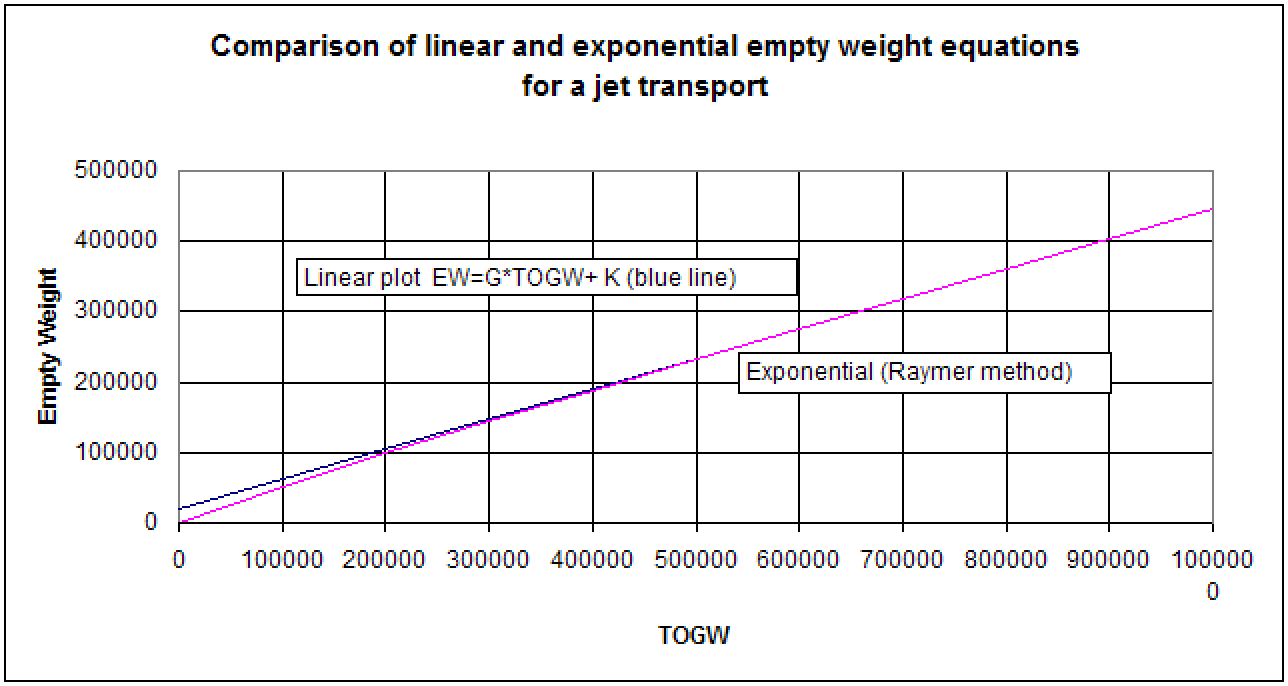

Fig 3.3.1 Comparison of Linear and Exponential Empty Weight Equations

For the straight line plot, K = 20,000 lb and G = 0.425. This seems reasonable that for aircraft above about 200,000 lbs the flight deck and avionics weigh about 20,000 lbs and everything else is proportional to W_0. You can repeat the exercise for other classes of aircraft, as illustrated in the spreadsheet 'Empty wt vs TOGW' located on the ADAC website under Support > Sample Spreadsheets.

A benefit of using a linear equation is that the iterative procedure described in Raymer Section 3.6.4 is no longer required. The non-iterative procedure is described in the Annotation to Section 3.5. However, in industrial grade sizing programs the relationship between empty weight and takeoff gross weight is not linear, and iterative procedures must be used, so it is important to learn how to use them.

There are some important differences in takeoff gross weight definitions between military and commercial aircraft. For military aircraft takeoff gross weight may be defined as

$$W_0 = W_{crew} + W_{payload} + W_{fuel} + W_{empty} \quad (3.3.3)$$

The payload (or fixed weight), using the Raymer definition, is defined as

- Non-expendables
  - Sensors
- Expendables
  - Bombs
  - Missiles
  - Cannon plus ammunition
  - Troops plus equipment
  - Cargo

For commercial aircraft the payload is defined as

- Passengers
- Passenger bags (both checked and unchecked)
- Cargo (excluding cargo containers)

The takeoff gross weight is defined as

$$W_0 = W_{payload} + W_{fuel} + W_{oe} \quad (3.3.4)$$

W_{oe} is the operating empty weight (OEW), which is

$$W_{oe} = W_e + W_{op} \quad (3.3.5)$$

W_e is the empty weight, usually defined as the manufacturer's empty weight (MEW), and W_{op} is the weight of the operational items, described in more detail in the Annotation to Raymer Section 15.2. Note that the crew weight has been absorbed into the operating weight empty, but so have a significant number of items, such as food and galley service equipment including carts, drinking water, cargo containers, cargo pallets, evacuation slides and life rafts, and numerous other items that add up to about 5-6% of OEW.

In Schaufele's (Ref 3.3.1) weight trend data (Figures 3.19 to 3.26), the weights shown are for operating empty weight (W_{oe}). The coefficients for the trend lines, expressed in the form $W_{oe} = A*W_0^B$, are

	Coefficient A	Coefficient B
Business Jets	1.85	0.89
Single Aisle Jet Transports	2.40	0.88
Twin Aisle Jet Transports	7.99	0.79

Unless other data are available, it is suggested that these values be used for estimating the operating weight empty for these classes of aircraft, assuming that the aircraft are built using aluminum for the structure. The coefficients in Raymer's book appear to apply to manufacturer's empty weight (W_e).

Reference

3.3.1 Schaufele, R., "The Elements of Aircraft Preliminary Design", Aries Publications, 2007.