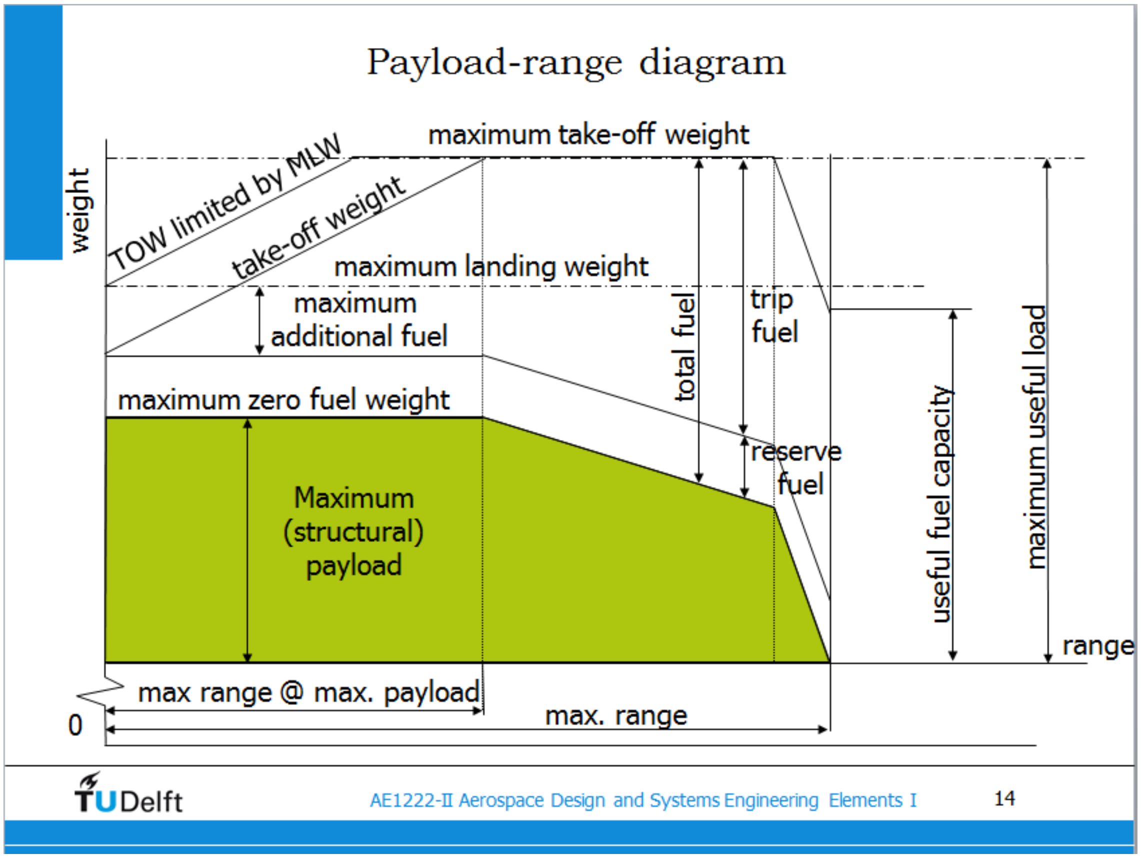
Payload Range Diagrams



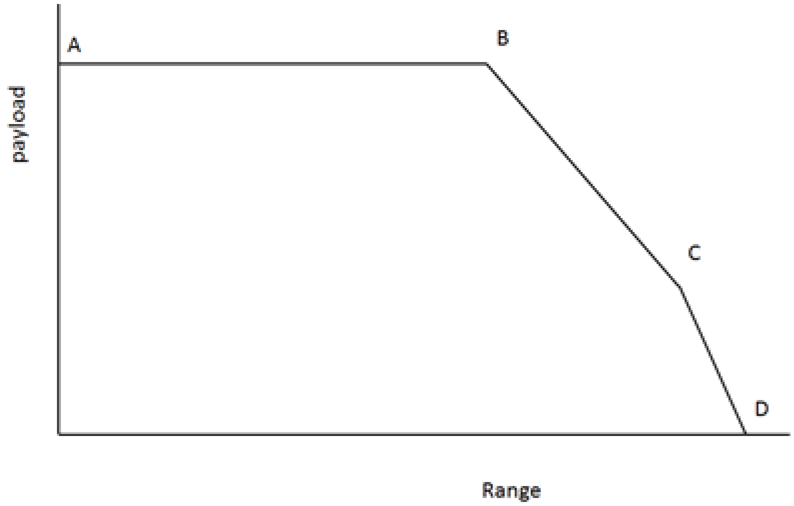
Explanation of the payload range diagram:

The payload range diagram illustrates the tradeoff relationship between the payload and the range of one single aircraft.
The payload refers to all the mass that is taken by an airplane, excluding fuel.

The structure of an aircraft is designed in order to be sustain a certain amount of loads. These loads depends on the amount of weight which is carried by the aircraft. Hence there is a value for the aircraft maximum take off weight, which can never be exceeded or the frame would collapse. Once the aircraft is loaded with the maximum amount of payload, the amount of fuel that can be embarked to fly a certain range is then limited by the maximum take off weight.

Once arrived at such point, any further range is achieved only by reducing the payload, which follows a nearly linear relationship.
Still, the amount of fuel that an airplane can carry is also limited. That is the reason that at one sudden point, the linear relationship changes drastically.

How to build up a payload range diagram:



1 - Collect all important data

In order to start building up a payload range diagram it is necessary to already have completed the weight estimation calculations.

You should know about the following: Wto; Woe; Wpl

Point A:
This point is simply W(pl,max), at R=0

Point B:
This point is W(pl,max), at R= max for max payload

Point C:
This point is W(pl) and R(max) when carrying the maximum amount of fuel. since the fuel tanks have a maximum amount they can carry, there is still space for payload. therefor, W(pl) is not zero here while W(f) is maximum.

Point D:
Here, W(pl)=0 and W(f)=max. The range is higher than at point C here, because you fly further with less weight aboard.
calculations:

Point B:

For point B you will need to focus on Brequets formula. Really, the only thing you have to do is find out the max range the airplane can fly @ max payload:

Propeller driven aircraft

$$R = \left(\frac{\eta_p}{g.c_p}\right)_{cruise} \cdot \left(\frac{L}{D}\right)_{cruise} \ln\left(\frac{W_4}{W_5}\right)$$

Jet driven aircraft

$$R = \left(\frac{V}{g.c_j}\right)_{cruise} \cdot \left(\frac{L}{D}\right)_{cruise} \ln\left(\frac{W_4}{W_5}\right)$$

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As you can see, most of the variables in this formula include constants. For a jet aircraft we should be provided with information similar to this:

The cruise data for this aircraft are as follows:
V_{cr} = 242 m/s
c_j = 15.3 mg/Ns (= 1.53*10^{-5} kg/Ns)
g = 9.81 m/s^2
$(L/D)_{cruise}$ = 17

Our only challenge is to find out what W4/W5 is, so we can use it in the formula. For this we must start off using this formula:

Wto(max) = Woe + Wpl(max) + Wf

Start off by finding out what the amount of fuel is the airplane can take on board @ maximum takeoff weight and max payload.

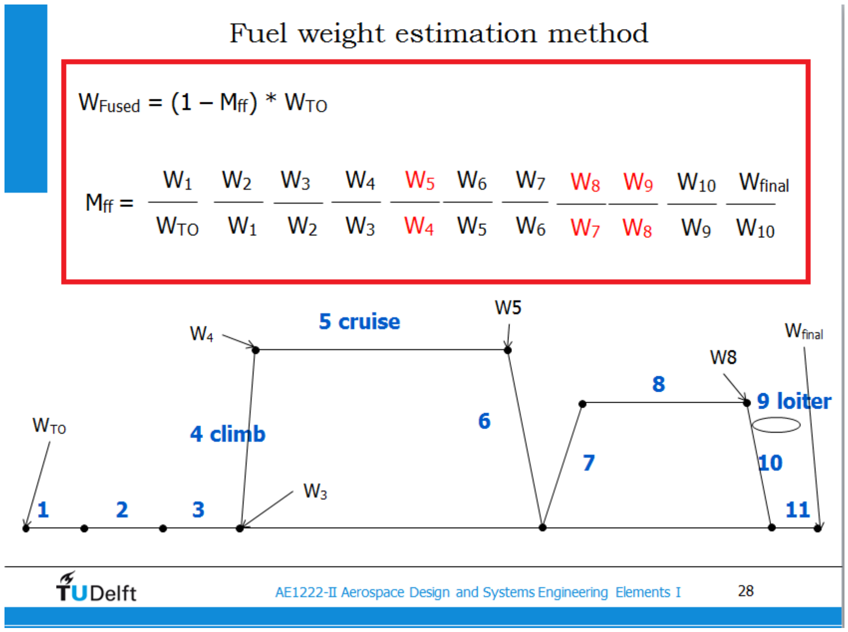
(Note: **Woe = We + Wtfo + Wcrew** and **We = a*Wto + b**)

Once you know that, you can find out the fuel fraction **Wf/Wto** for the aircraft.

You should then be given a table containing information of fuel fraction at different phases similar to the one shown below. Your task is to find out the fuel fraction for cruise *(Note: You might need to include loiter and diversion phases!)*

1. Start-up - 0.990
2. Taxi - 0.990
3. Take-off - 0.995
4. Climb - 0.980
5. Cruise - unknown
6. Descent - 0.990
7. Landing - 0.992

Recall that:



So we have already Wf/Wto, we can find out Mff:

$$M_{ff} = 1 - \frac{W_F}{W_{TO}}$$

Once we know Mff, we can find out W5/W4.

Then take the inverse of it, and you finally have W4/W5, which you needed in order to use Brequets formulas and find point B.

Point C

For Point C you must be given how much fuel your aircraft can take @ max Wto. With it you can then calculate how much payload can be carried by again using:

Wto(max) = Woe + Wpl + Wf(max)

And then, the rest, yes, you guessed it, is just the same procedure as to find the range for point B: just follow this:

- find fuel fraction
- find Mff
- find W5/W4
- calculate Range

Point D:

In this case, all payload is taken out and you fly at max Wf in order to achieve maximum range.
Therefore our formula for weights reduces to:

$$\mathbf{Wto = Woe + \cancel{Wpl} + Wf_{(max)}}$$

and again we must find Wto.
Once done that, just, yes yes, repeat what you did for point B and C.