

## 17.2.4 Range

Raymer mentions the step-climb procedure for commercial cruise  $C_L$  optimization in order to stay at a near-constant  $L/D$ . At altitudes up to 60,000 ft, aircraft flying of the United States and other areas, fly in reduced vertical separation minima (RVSM) airspace to maintain a 1000 ft vertical separation, as illustrated in Fig. 17.2.4.1. Industrial-strength mission sizing programs will have the capability of performing the required step-climb during cruise. Typically the program will search available altitudes during cruise and find the altitude at which the aircraft will maximize specific range (nm/gal) for a given aircraft weight and Mach number. The program will then have the aircraft climb to that altitude.

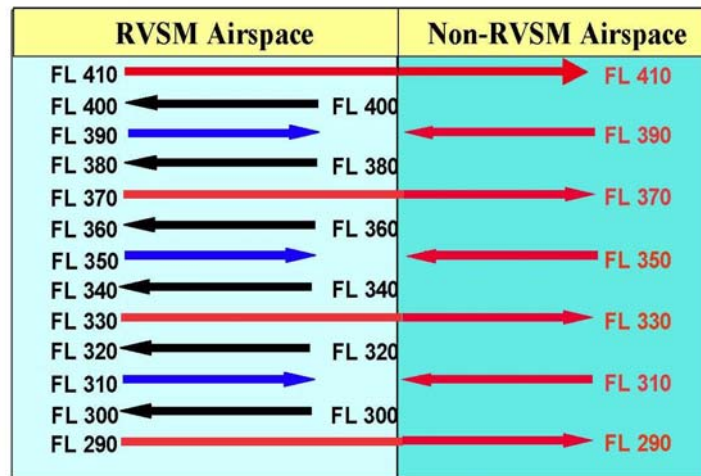


Fig 17.2.4.1 RVSM and Non-RVSM Airspace

Typically the flight management computer will tell the pilot the optimum altitude (shown in Fig. 17.2.4.2 as FL356) and the pilot will have to get authorization from air traffic control (ATC) to climb to the altitude that best matches the optimum. In this particular case the pilot is already flying at FL350, and is thus flying at the closest permitted altitude.



Fig. 17.2.4.2 Boeing 737 Flight Management Computer: Cruise Display  
(This photo was taken before 2005)

On the Boeing 747-400, the Honeywell FMC can also adjust the Mach number so that at start of cruise on a transpacific flight the recommended Mach number might be Mach 0.86, but at end of cruise the aircraft will slow down to Mach 0.83. The pilots can also bias the results (by ranking their preference on a scale of 1 to 10) in favor of fuel economy or speed on the FMC.

### Payload-Range Plot

Payload-range data can be obtained from many sources, both online and in print. Great care must be taken in the use of these figures because the underlying assumptions are not always stated. The payload-range plot goes at least some of the way towards clarifying the situation.

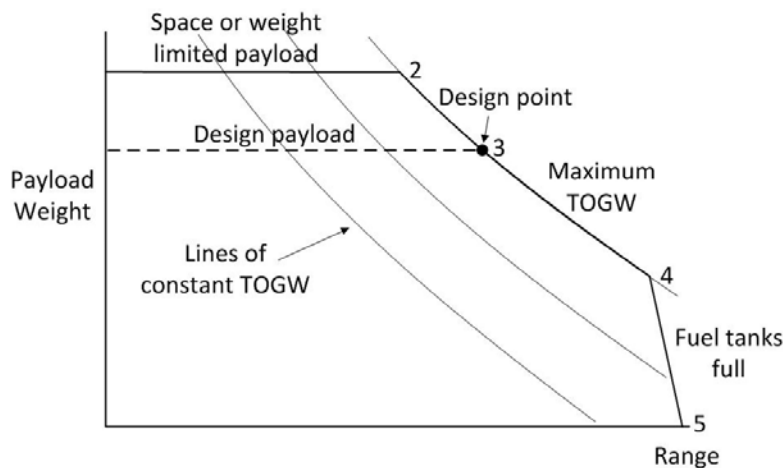


Figure 17.2.4.3 Payload-range Plot

The vertical axis is the payload weight. The curved lines shown in Figure 17.2.4.3 are not displayed on a standard payload-range plot, but they show how payload can be traded for increased fuel so as to increase range at a constant takeoff gross weight. The top horizontal line is the maximum payload, limited by space or possibly airframe strength. The limit of this line is at the maximum TOGW for the aircraft. Typically the fuel tanks are not full, even when the payload is reduced to the design payload. This permits operational flexibility for the aircraft so that it can fly at longer ranges with reduced payload. Once the fuel tanks are full, the only possible increase in range is to offload more payload and reduce TOGW.

It's important that all the underlying assumptions be stated on a payload-range plot. In particular, the complete mission should be stated explicitly, including distance to alternate and reserves. The cruise Mach number assumptions should also be stated. If the complete mission is not defined, it must be assumed that no reserves are included, which would not be unusual, especially for a business jet payload-range plot. Business jet reserves are normally based on NBAA requirements, but they are fairly flexible, so the best way to compare business aircraft capabilities is to exclude reserves.

The payload-range plot is therefore useful for comparing the capabilities of different aircraft, but not sufficient for route planning.

The design point payload-range point was established in the initial sizing of the airplane. The other significant points are described below. It is assumed that the mission is defined in an Excel spreadsheet and that the Solver Add-In is installed.

#### Point 4: Range with fuel tanks full

Estimate the fuel volume using the following equation from Ref. 17.2.4.1, Section B-3.

$$V_f = 0.54 \frac{S^2}{b} \left( \frac{t}{c} \right)_r \frac{1 + \lambda \sqrt{\tau} + \lambda^2 \tau}{(1 + \lambda)^2}$$

where

S = gross wing area

b = wing span

$(t/c)_r$  = wing thickness/chord ratio at the wing root

$\lambda$  = taper ratio

$\tau = (t/c)_t / (t/c)_r$

This equation takes account of the fact that the wing tank extends to only about 85% of the wing span so as to leave a dry bay at the wing tip to reduce the probability of a fire from a wing tip lightning strike. Dry bays are also in the vicinity of the engine pylon in case the engine disintegrates and parts pass through the wing. Additional volume is taken up by fuel pumps and lines within the tanks. Assume the aircraft is using Jet A with a density of 50.4 lb/ft<sup>3</sup> per ASTM-D-1655 (Ref 17.2.4.2) This will give you the total weight of fuel available when the tanks are full.

From mission analysis, find the total weight of fuel used for the design mission, including reserves. Calculate the difference between the maximum fuel available and design mission fuel including reserves. For Point 4, you can decrease payload and add the corresponding weight in additional fuel so that the value of TOGW is the same as that for Point 3.

If you are using a spreadsheet, you can copy your original mission on to a new sheet. Using the Solver Add-In, you can find a new range with a reduced payload by requiring Solver to change the cruise range so that the cell which contains the value of OEW based on mission calculations retains the same value as for the design range. The TOGW remains the same as the value which was established for the design point.

#### Point 2: Range at space or weight limited payload

If your airplane has extra capacity in the cargo hold, or can increase payload with a single-class cabin, you can increase the payload, and repeat the exercise to find Point 2.

#### Point 5: Range with zero payload

Copy your original mission onto a new sheet again (this is so you can keep all the results separate). For Point 5, reduce the TOGW to reflect removal of the number of passengers and baggage established for Point 4 (this ensures that the fuel tanks are full). You must also set the payload to zero. Now use Solver to change the cruise range again so that the cell which contains the value of OEW based on mission calculations again has the same value as for the design range.

#### References:

- 17.2.4.1 Torenbeek, Egbert, "Synthesis of Subsonic Airplane Design", Delft University Press, 1982.
- 17.2.4.2 Anon, "Aeronautical Vestpocket Handbook", United Technologies, Pratt & Whitney Division, 1986.