Initial Sizing

Aircraft Sizing

- One of the most important parts of aircraft design
- Determines how big the aircraft is (specifically mass)
- Based on the mission requirements
  - We know what the aircraft does – its in the specification
  - We need to determine how big it is.
- One method (the fastest) is to use the mass of the aircraft we will replace
- We will use a *slightly* more sophisticated method
  - However, it is still based on using past data
- It is also an iterative process

Take-off Weight Build-up

Break up the take-off gross weight into

- Crew
- Payload weight
- Fuel weight
- Empty weight, which includes
  - Structure
  - engine
  - Landing gear
  - Fixed equipment
  - Avionics
  - Etc….. (everything else!)

Take-off Weight Build-up

Break up the take-off gross weight into

We can express fuel and empty weight as fractions of the gross take-off weight

Which can be rearranged

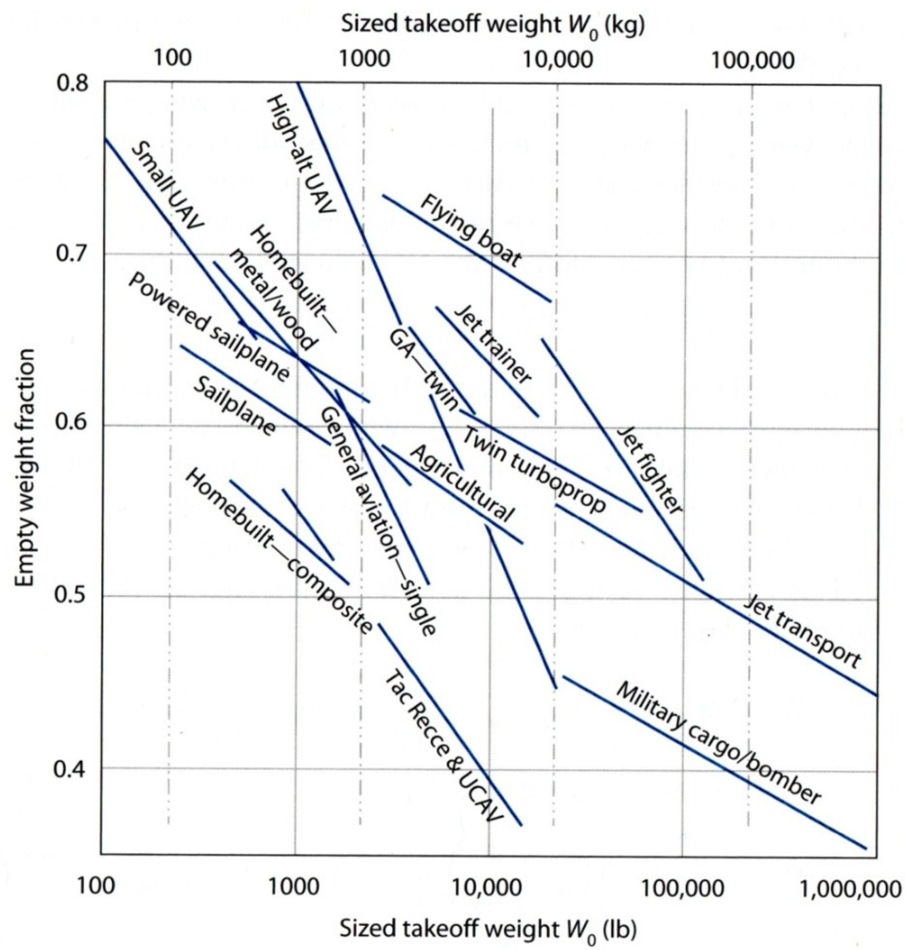
Now as the crew and payload weights are usually provided in the specification we need to determine the fuel and empty mass fractions, which in the first instance, we will estimate.

$$W_0 = \frac{W_{crew} + W_{payload}}{1 - \left(\frac{W_f}{W_0}\right) - \left(\frac{W_e}{W_0}\right)}$$

?

Empty Weight Estimate

- The initial empty weight will be estimated from the fraction of empty to take-off weight fraction.
- In future iterations this can be improved by adding the mass of the different components.
- Empty weight fraction will be estimated from historical data.
    - Typically lies between 0.3 and 0.7 – quite a range!!



Empty Weight Estimate

Type	A	C
Sailplane – unpowered	0.83	-0.05
Sailplane – powered	0.88	-0.05
Homebuilt – metal/wood	1.11	-0.09
Homebuilt – composite	1.07	-0.09
General aircraft – single engine	2.05	-0.18
General aircraft – twin engine	1.40	-0.10
Agricultural aircraft	0.72	-0.03
Twin turboprop	0.92	-0.05
Flying boat	1.05	-0.05
Jet trainer	1.47	-0.10
Jet fighter	2.11	-0.13
Military cargo/bomber	0.88	-0.07
Jet transport	0.97	-0.06
UAV – tactical recce & UCAV	1.53	-0.16
UAV – high altitude	2.48	-0.18
UAV small	0.86	-0.06

- Empty weight fraction will be estimated from historical data.
  - Typically lies between 0.3 and 0.7 – quite a range!!
  - Historical data follows the following trend

Where A and C are constants which are dependent on the type of aircraft.

Note: variable sweep wings are heavier than fixed wings, to account for this multiply the empty weight fraction by 1.04.

Based on limited data of composite aircraft multiply the empty weight of these aircraft by 0.95.

$$W_0 = \frac{W_{crew} + W_{payload}}{1 - \left(\frac{W_f}{W_0}\right) - \left(\frac{W_e}{W_0}\right)}$$

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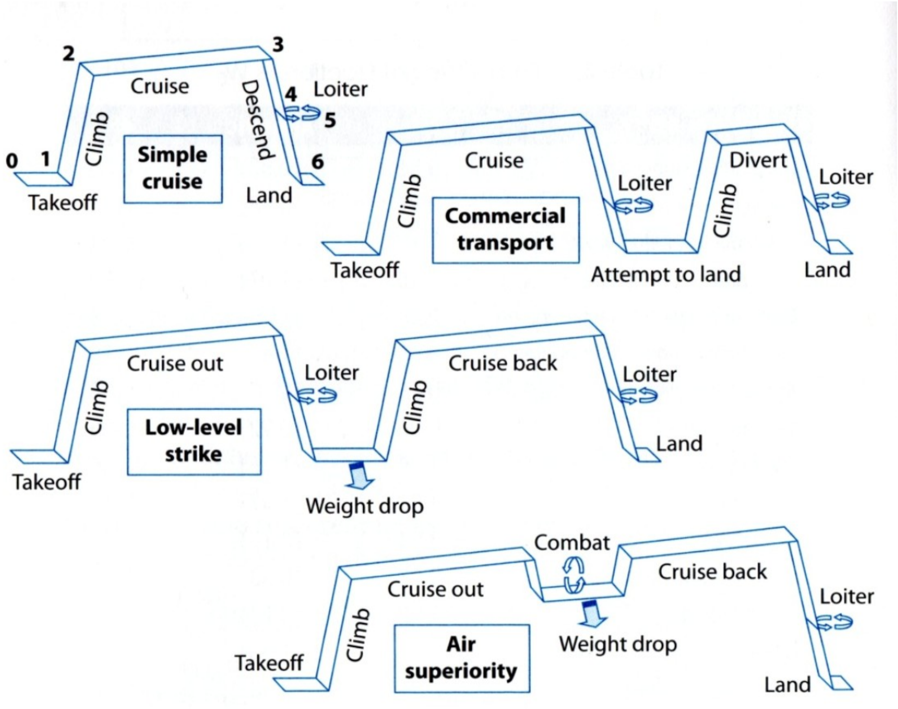
Fuel Fraction Estimates

- Highly dependent on the mission profile
- Therefore need to *fly* the mission
- In the first instance, fuel can be considered to be proportional to the aircraft weight so fuel fraction can be estimated based on the mission flown.

Mission Profiles



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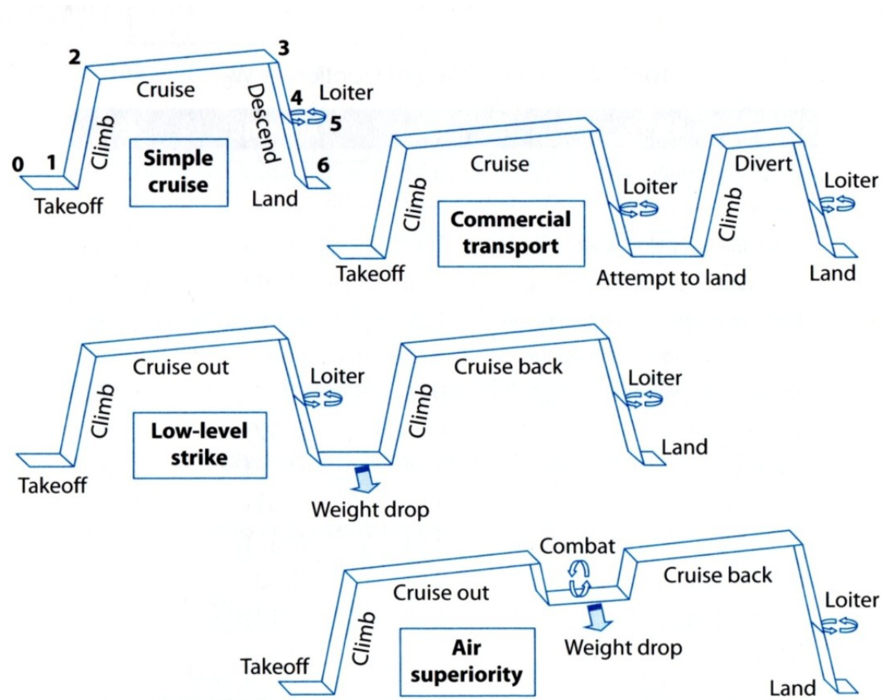
Mission Profiles

Highly dependent on the specification/ requirement

- Include contingencies, such as,
  - 30 minutes cruise for VFR flight
  - 45 minutes cruise for IFR flight
  - Loiter, then diversion to alternative airport (commercial IFR)
- See regulations (JAR23/25 and FAR23/25 as appropriate)



Mission Profiles

Mission segments, *legs*, are usually numbered

- Leg 1 usually refers to engine warm-up and take-off
- Similarly the final leg corresponds to landing

For initial sizing the following fractions are reasonable for take-off, climb and landing (unless you want to calculate them yourself).

Mission Segment	
Warm-up and take-off	0.970
Climb	0.985
Landing	0.995

Mission Profiles

For any mission segment we want to determine the weight fraction which can be determined by the Breguet range and endurance equations.

For range

or

R	= Range
C	= Specific fuel consumption
V	= Velocity
L/D	= Lift to drag ratio

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Mission Profiles

For any mission segment we want to determine the weight fraction which can be determined by the Breguet range and endurance equations.

For Endurance

E or

E	= Endurance
C	= Specific fuel consumption
V	= Velocity
L/D	= Lift to drag ratio

or

C?

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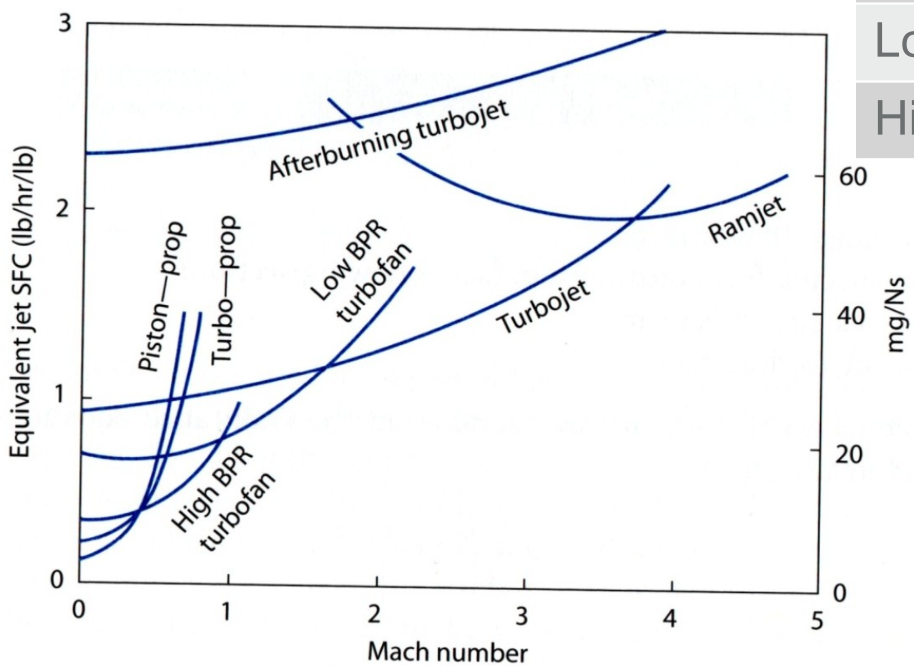
Specific Fuel Consumption

Specific fuel consumption is the fuel consumption per unit of thrust. This is dependent on Mach number and the type of power plant used as shown below.

Typical Jet SFC (mg/Ns)	Cruise	Loiter
Pure turbojet	25.5	22.7
Low-bypass ratio turbofan	22.7	19.8
High bypass ratio turbofan	14.1	11.3



Specific Fuel Consumption (propeller)

For a propeller powered aircraft the SFC equivalent to a jet-engined SFC can be calculated from the power specific fuel consumption ().

Where V is the aircraft velocity and is the propeller efficiency (typically 0.8).

Typical Propeller SFC (mg/Ws)	Cruise	Loiter
Piston-prop (fixed pitch)	0.068	0.085
Piston-prop (variable pitch)	0.068	0.085
Turboprop	0.085	0.101

Lift to Drag Ratio Estimation

Many different methods to estimate the cruise and loiter L/D ratio – also see Roskam for alternative method.

How do we estimate the L/D ratio for something we have not designed yet?!?

- Aspect ratio? – induced drag….
- Wetted area? – parasitic drag…

Neither tells the whole story.

It turns out that the "wetted aspect ratio" is a good predictor of L/D ratio for preliminary design, where,

Where A is the aspect ratio, b is the wing span, and the ratio is the ratio of the wetted area to the reference area.

or

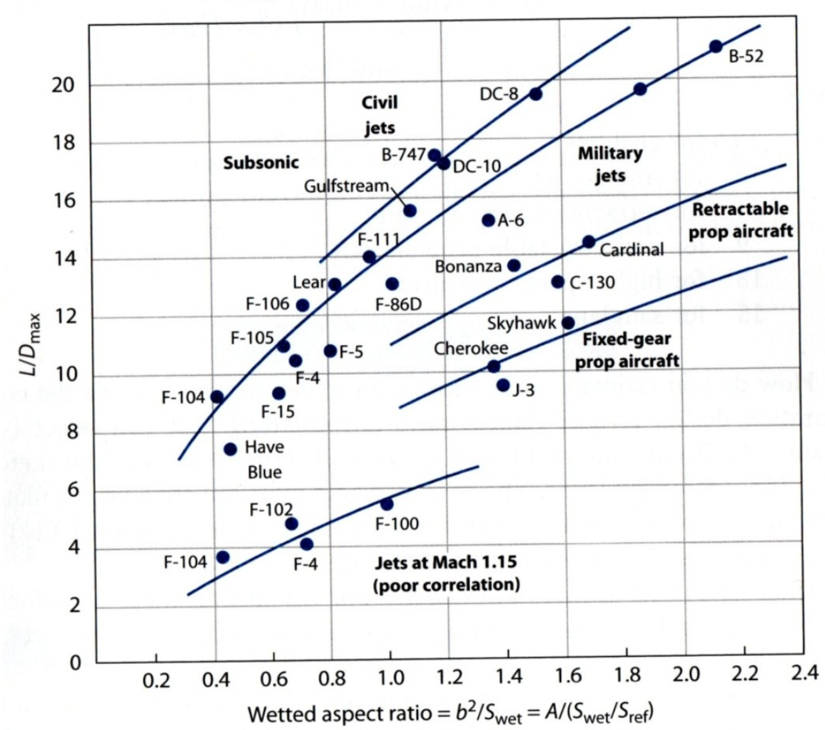
?

Lift to Drag Ratio Estimation

Where A is the aspect ratio, b is wing span, and the ratio is the ratio of the wetted area to the reference area.

Each of these lines can be described by
, where

	Type
15.5	Civil jets
14	Military jets
11	Retractable prop aircraft
9	Non-retractable prop aircraft
13	High aspect ratio aircraft
15	Sailplanes



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But where does the ratio come from?

Lift to Drag Ratio Estimation

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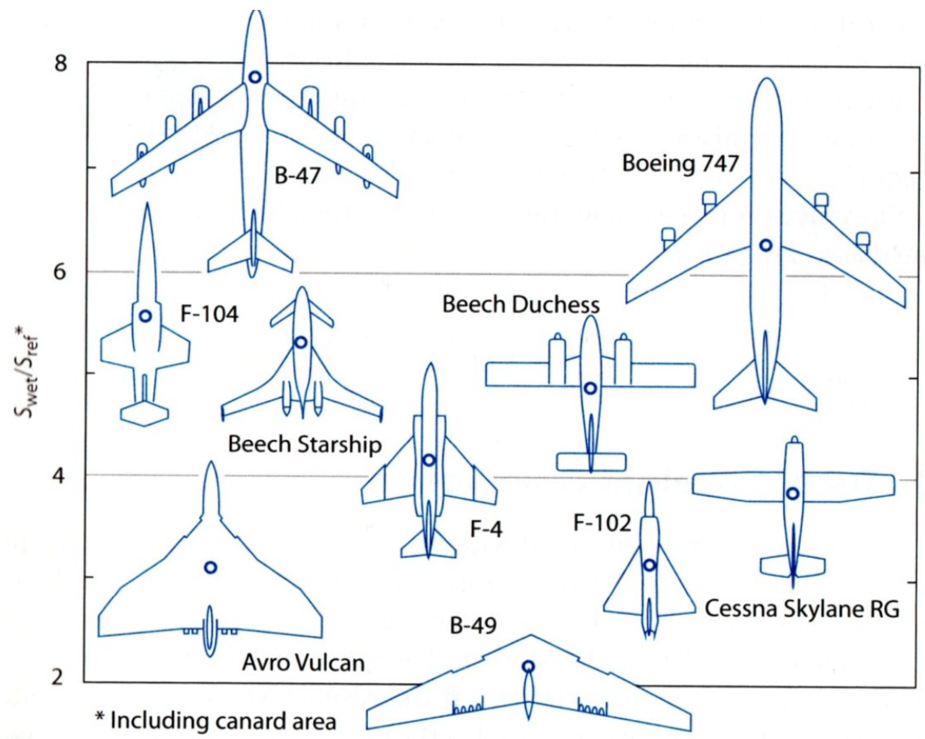

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The most efficient cruise and loiter velocities for jet and propeller aircraft occur at different conditions.

	Cruise	Loiter
Jet		
Prop		

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Fuel Fraction Estimate

By multiplying the flight segment weight fractions together the fuel weight fraction can be obtained, including a 1-2% factor to account for unusable/trapped fuel etc.

Putting it all together

We have two equations relating empty weight to the gross take-off weight

(from regression of historical data)

(from the weight build-up calculations)

We need a solution which satisfies both equations we can do this by

1. Producing a table of guesses, from these calculating the empty weight fraction (using the first equation above), then using the second to calculate - and find where the gross take-off weight is the same.
2. Plot the weight empty weight fraction from both equations and see where they cross.