Aerospace Vehicle Design And System Integration 3

CADE30007

(AVDASI 3 - Aircraft Propulsion, Performance and Sustainable Operations)

Aircraft Performance

Lecture 2

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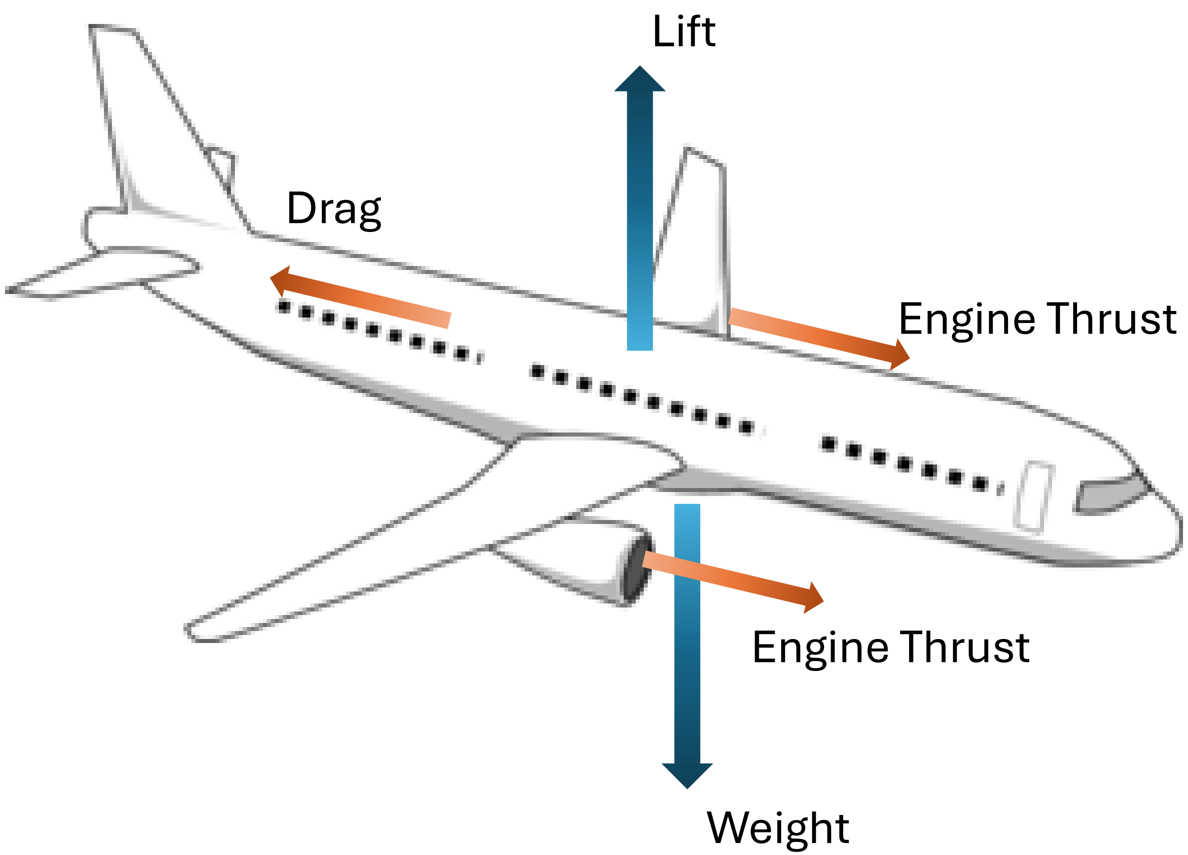
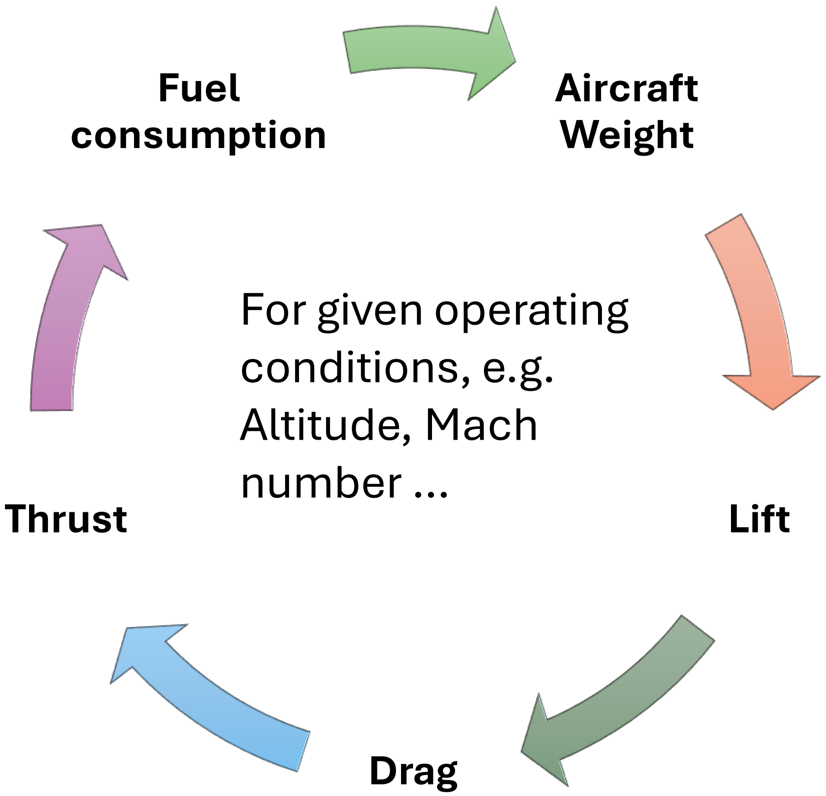
Overview

- Performance in climb, cruise and descent
- Useful parameters
- Fixed Wing Performance Tool

Performance of Civil Airliners

A Simplistic View of Performance Model





Data required for an Aircraft Performance Calculation

Mission Definition

Operating conditions

Required range

Take off and landing requirements

Mass

Payload

Fuel Load

Operators Mass Empty

Maximum Take-off Mass

Drag Data

Zero Lift Drag

Induced Drag

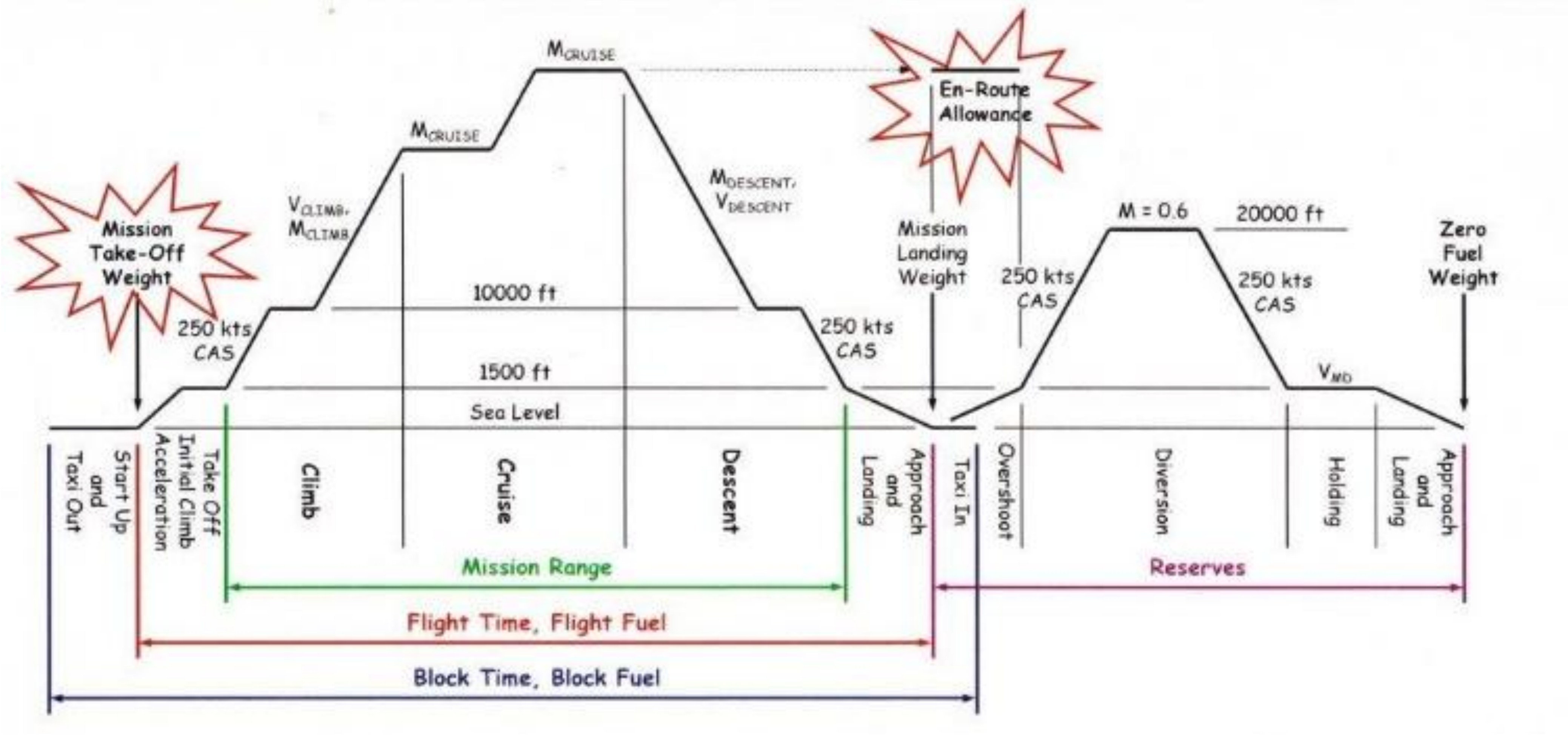
“Wave Drag”

Drag due to Reynolds Number

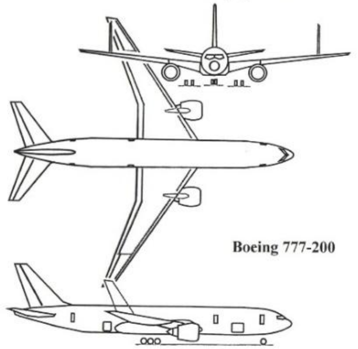
Engine Data

Thrust & Fuel Flow across the Flight Envelope

Typical Mission Profile for a Civil Airliner



Critical **Sizing Conditions**
Subsonic Transport Aircraft



Fuselage
- Payload

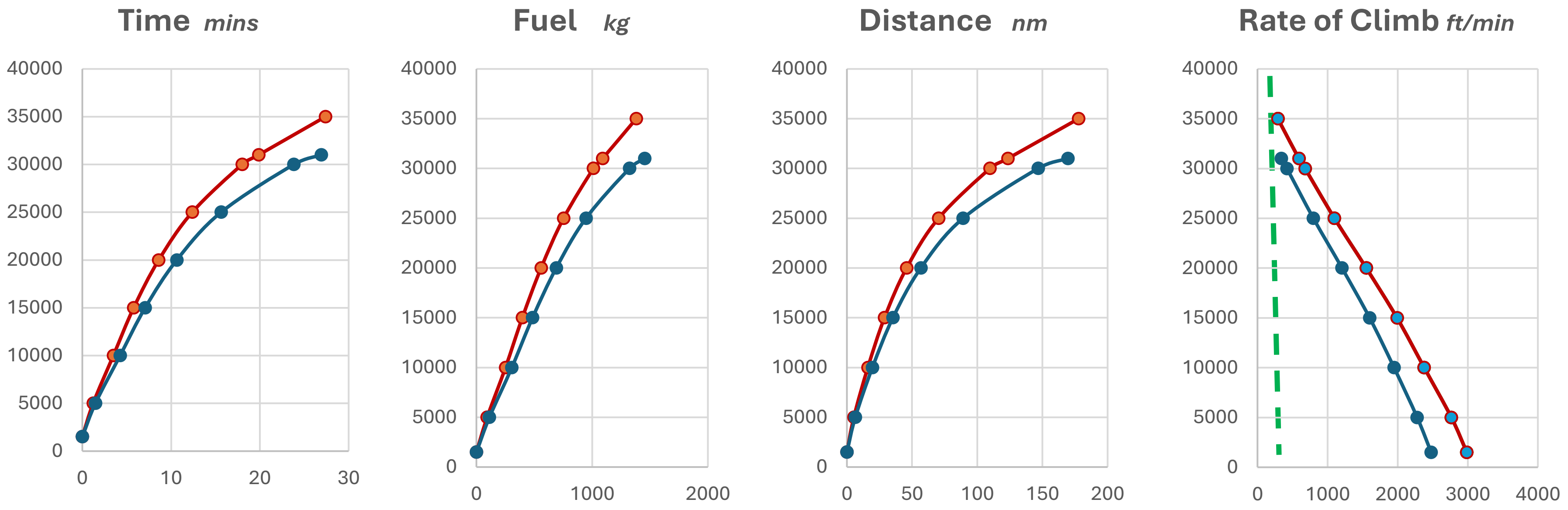
Wing Area
- Cruise Mach Number dependent on Range hence Wing Sweep.
- Lift Coefficient at Top of Climb & for Cruise
- Aspect ratio for minimising Drag.
- Lift Coefficient, with flaps for Take-off & Landing (Approach Speed)
- Sufficient Volume in wing for fuel.

Control Surfaces
- Balance, Engine out, Control (longitudinal & lateral) etc.

Engine
- **Take-off**
  - Sufficient thrust to meet take-off distance.
- ***Climb***
  - Sufficient thrust to give the aircraft a time to climb to at cruise altitude with a residual rate of climb of at least 300 ft/min.
- ***Cruise***
  - Sufficient thrust to sustain the cruise Mach Number following at take-off at Max Mass.
- ***En-route clearance***
  - Sufficient thrust to allow the aircraft to maintain altitude with an engine failed

Climb Performance

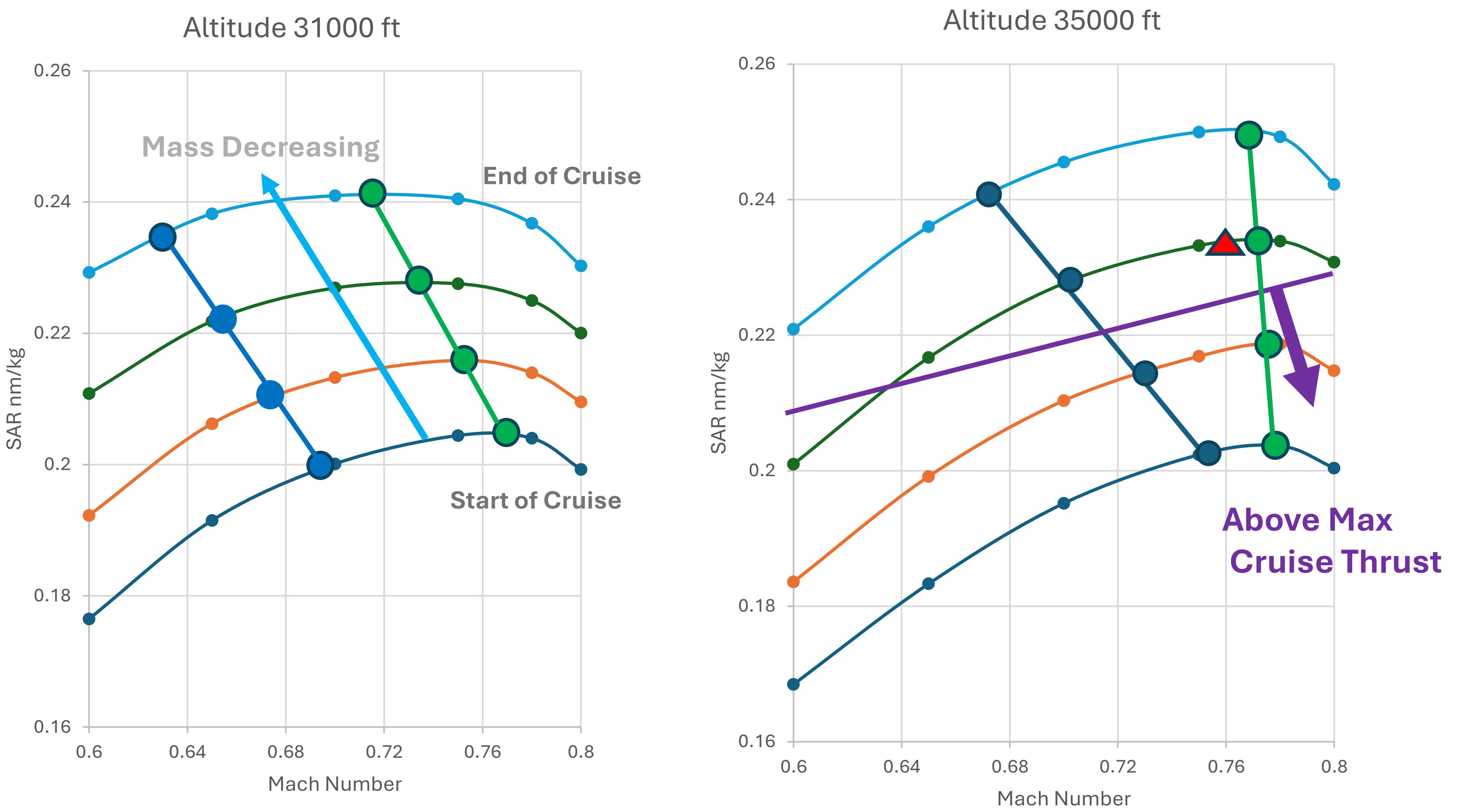
Climb Profile: 250/280 CAS / M = 0.76



Key: Take off Max ToM   Take off Reduced ToM *(for half range)*   300 ft/min Rate of Climb

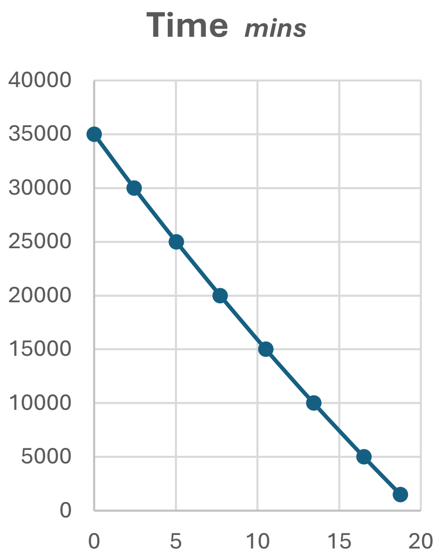
A useful empirical rule is that the top of climb Mach Number to be 0.02M less than the Cruise Mach Number

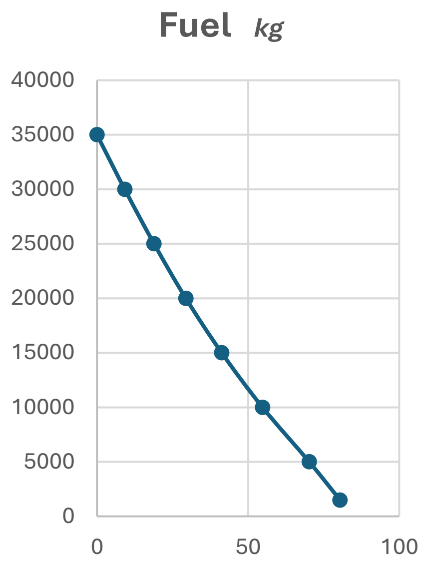
Cruise Performance *Specific Air Range Plots*

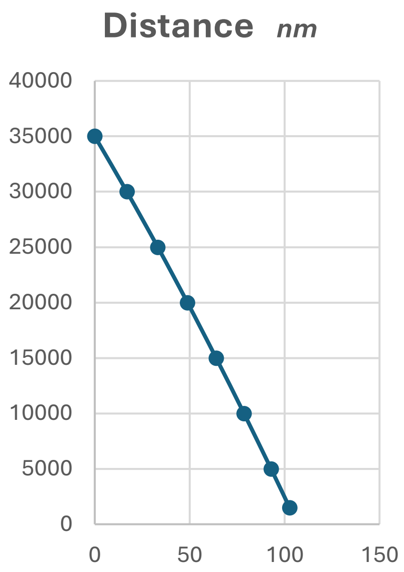


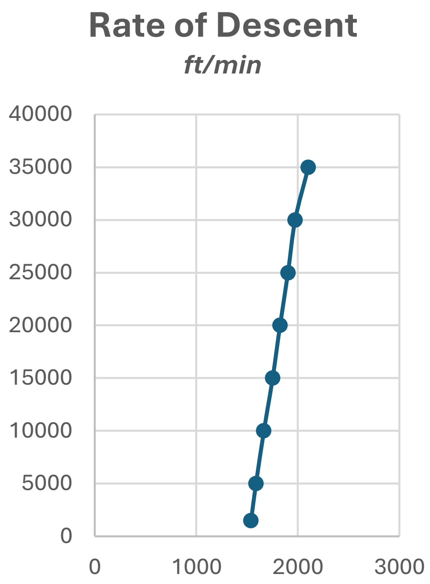
Key: Minimum Drag Maximum Specific Air Range Maximum Cruise Thrust 300 ft/min Climb Thrust

Descent Performance









Key: Descent Speed Profile 250 knots CAS Mass at end of cruise
Cabin Altitude 8000 ft. The maximum rate of change of pressure in the Cabin must not exceed 300 ft/min. Hence Descent Time to 1500 ft should be > 22 mins.

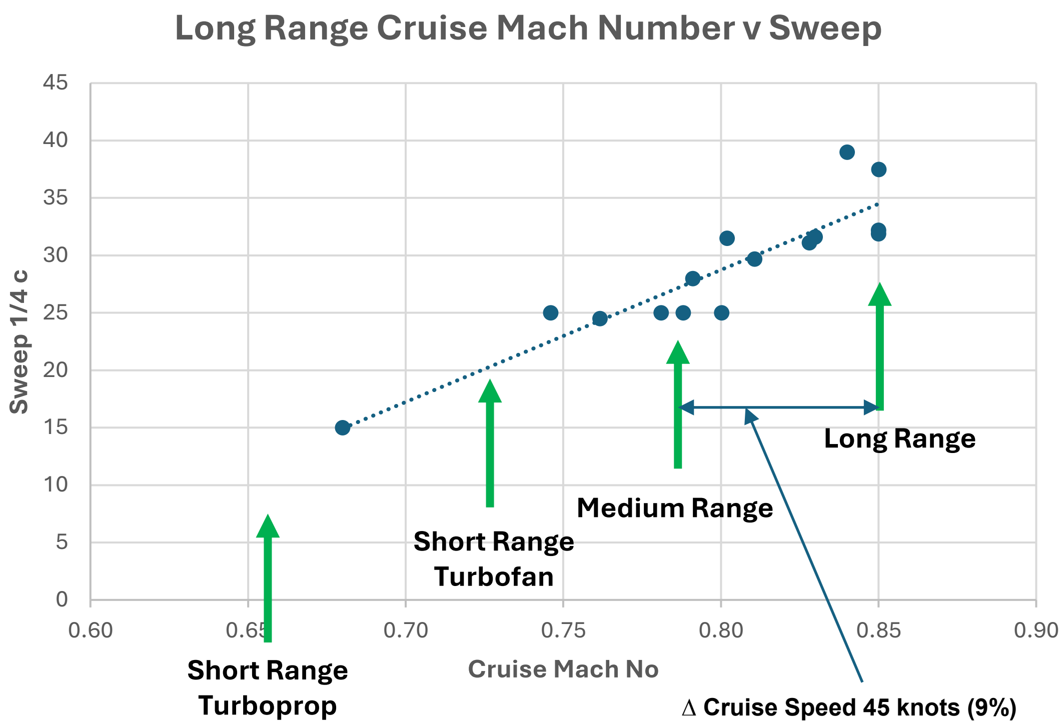
Cruise Speed & Initial Cruise Altitude

The Airline Specification defines Cruise Speed & Initial Cruise Altitude (ICA):

- **Long Range Aircraft Twin Aisle (250 – 500 + seats) Range 5000 nm +**
  - *Long Range Cruise Speed M = 0.83 – 0.85 ICA at least 35,000 ft*
- **Medium Range Single Aisle (150 - 250 seats) Range 3000 nm**
  - *Long Range Cruise Speed M = 0.76 – 0.80, ICA at least 35,000 ft*
- **Short Range Turbofan Single Aisle (70 – 150 seats) Range 1500 nm**
  - *Cruise Speed M = 0.7 – 0.76 ICA at least 31,000 ft*
- **Short Range Turboprop Single Aisle (50 – 150 seats) Range 1200 nm**
  - *Cruise Speed 0.5 – 0.7, ICA at least 25,000 ft*

Wing Loading & Wing Sweep

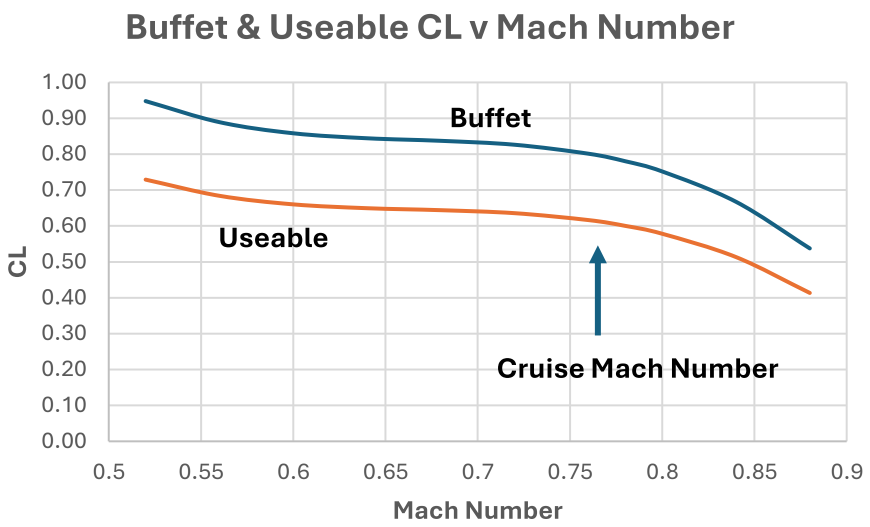
- Wing loadings (at take-off mass) for a new design in the range 600–650 + kg / m^2 – derivative versions may be higher.
- Set by cruise performance & take-off & landing and type of flap system.
- Wing sweep largely set by cruise speed:



Note: the higher the sweep the better the fuel burn at high Mach Numbers, at the expense of wing weight & low speed & take off performance.
Tendency for:
Long range – large airfields & long runways.
Short range small airfields & short runways.

Cruise Speed & Lift Co-efficient

- At typical start of cruise conditions:
  - Altitude 35,000 ft
  - Cruise Mach Number
  - Mass 97% of take-off mass)



- C_L needs to be within buffet boundary*

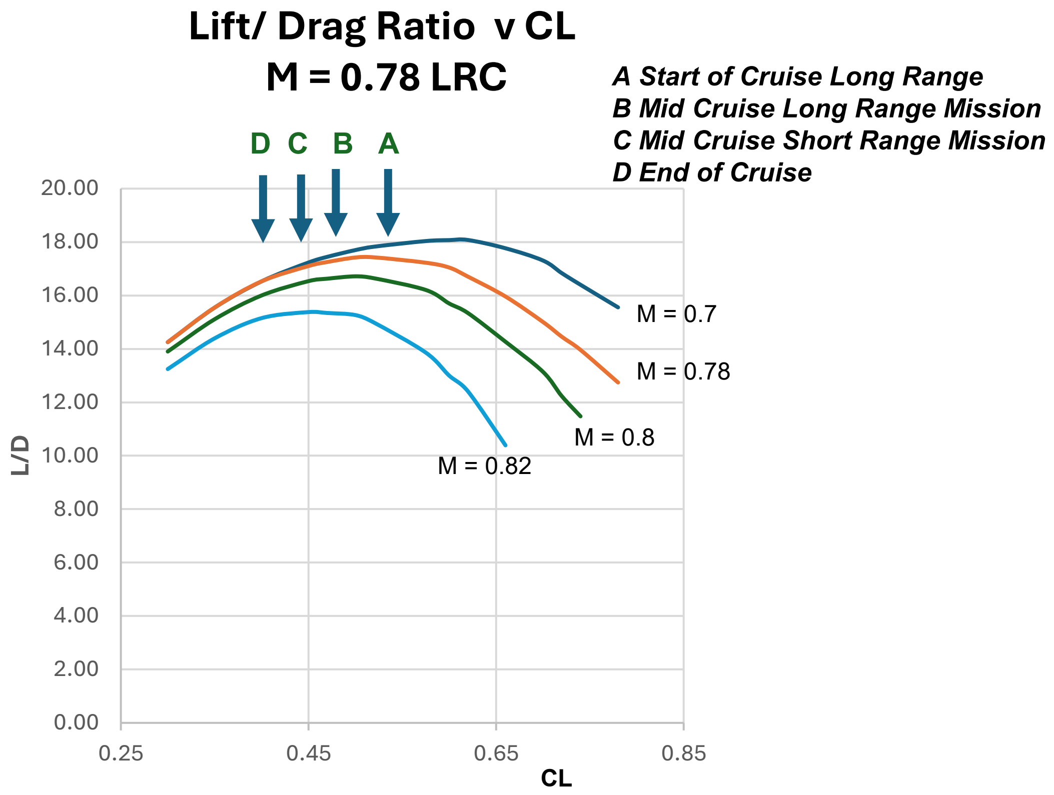
  * *beginnings of wing stall*

Example:
Take-off Wing Loading 640 kg/m²
Cruise Mach Number = 0.78
CL at 35000 ft:
Factor C_{LBuff} / $CL_{useable}$ = 1.3
Buffet = 0.78
Useable = 0.6

Drag Characteristics

$$C_{DTot} = C_{Do} + K\,C_L^2 + \Delta C_{Dw} + \Delta C_{DRe}$$

- C_{DTot} = Total Drag Co-efficient
- C_{Do} = Zero Lift Drag at a Reference Reynolds Number
- K = Induced Drag Factor
- C_L = Lift Coefficient
- ΔC_{Dw} = Increment in drag due to shock wave effects a function of C_L & Mach Number
- ΔC_{DRe} = Increment in Drag due to difference in R_e from Reference R_e ~ *(can be ignored in these studies)*

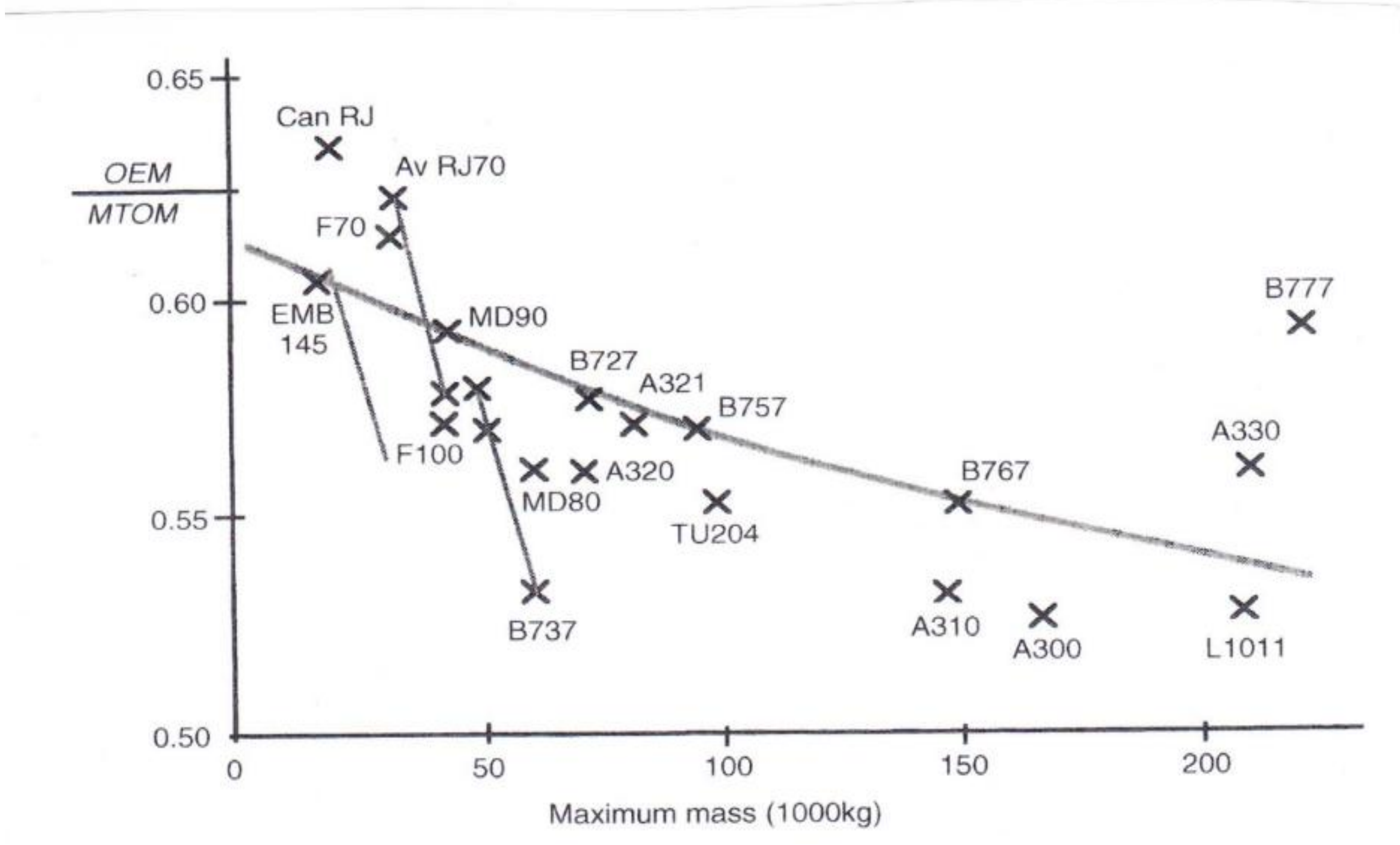


Note: with a take off wing loading in the range 600 - 650 kg/m², the range of CL's (clean) that the aircraft will experience are in the range 0.3 to 0.6. For a modern wing. the max operating C_L to avoid buffet at the Long Range Cruise Mach Number will be of the order of 0.6.

Some Useful Numbers

For a "conventional" Turbo-Fan powered Airliner there are a number of key parameters

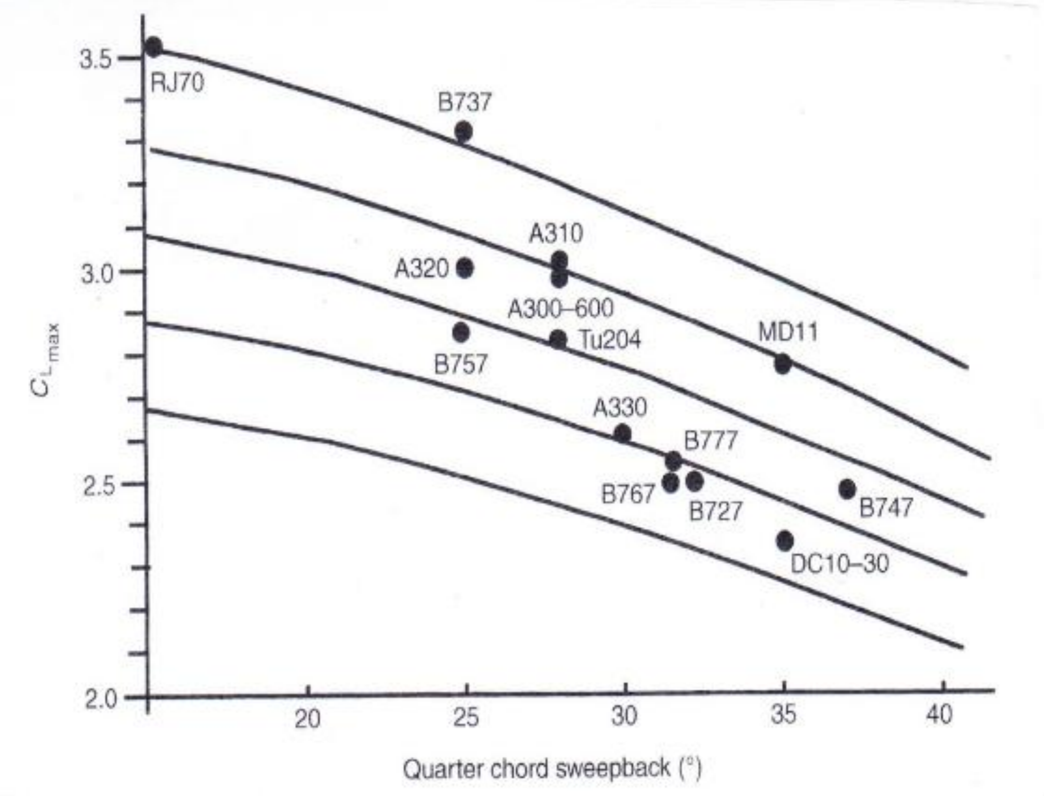
- Wing Loading:
  - 600 kg/m^2 (initial variant)
- Thrust/Weight Ratio
  - Four Engines ~ 0.25
  - Three Engines ~ 0.27
  - Two Engines ~ 0.3
- Empty Mass Fraction:
  - 0.53 to 0.57
- Cruise Mach Number:
  - 0.78 (medium range) to 0.84+ (long range)



Some Useful Numbers

For a "conventional" Turbo-Fan powered Airliner there are a number of key parameters

- Quarter Chord Sweep
  - 25° (medium range) : 30°+ (long range)
- Aspect ratio
  - 9 to 11
- Lift Coefficient at start of Cruise
  - $C_L \sim 0.6$
- Lift/Drag Ratio
  - 18 (medium range) : 20+ (long range)
- Initial Cruise Altitude
  - 35,000 ft
- C_{LMax} at for Take-off & Landing
  - 2.5 to 3.5



Typical Drag Values

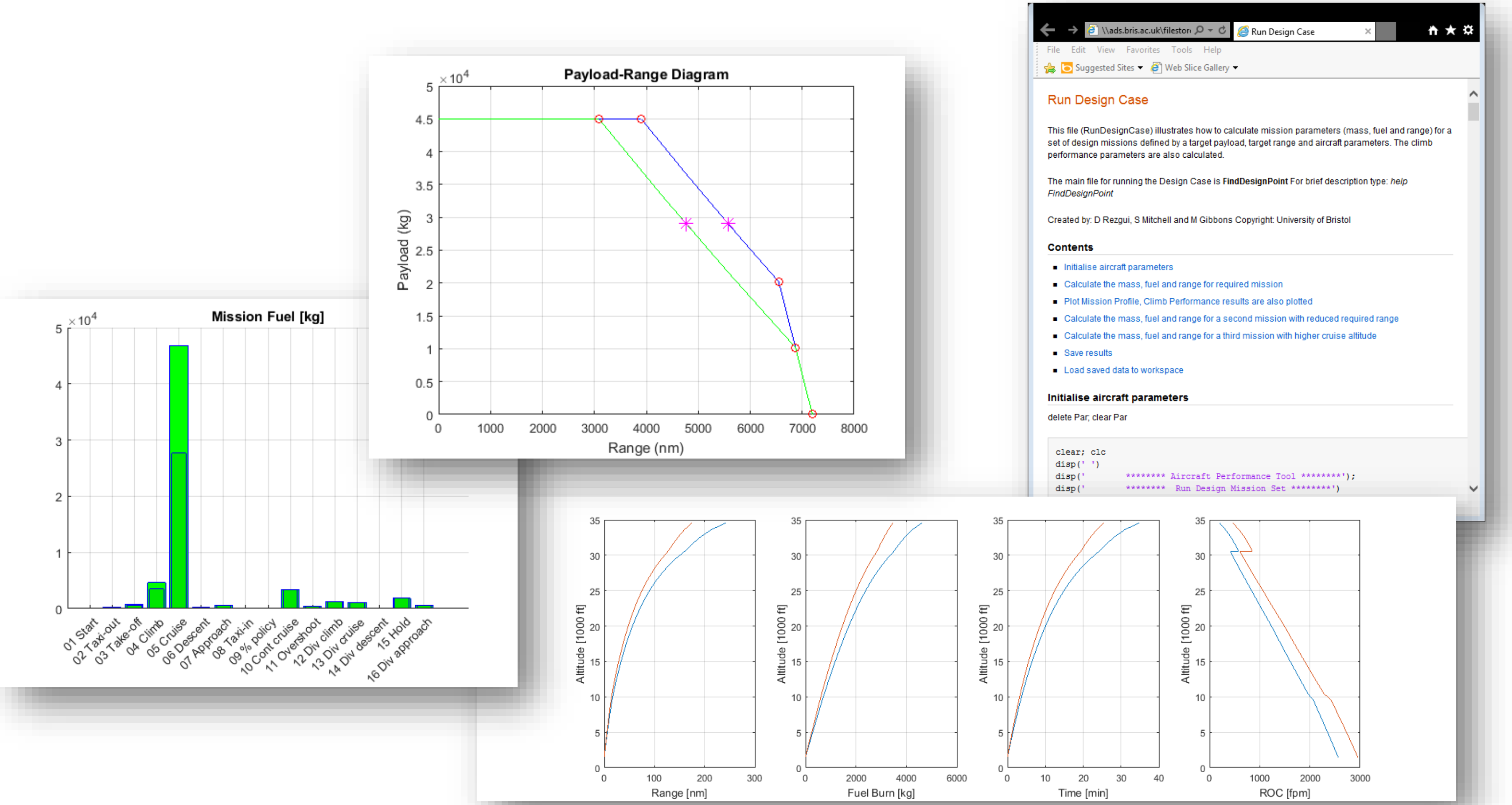
C_L = 0.6

L/D = 20

C_{Dtot} = 0.03 (300 counts)

ΔC_{DW} = 5 + counts

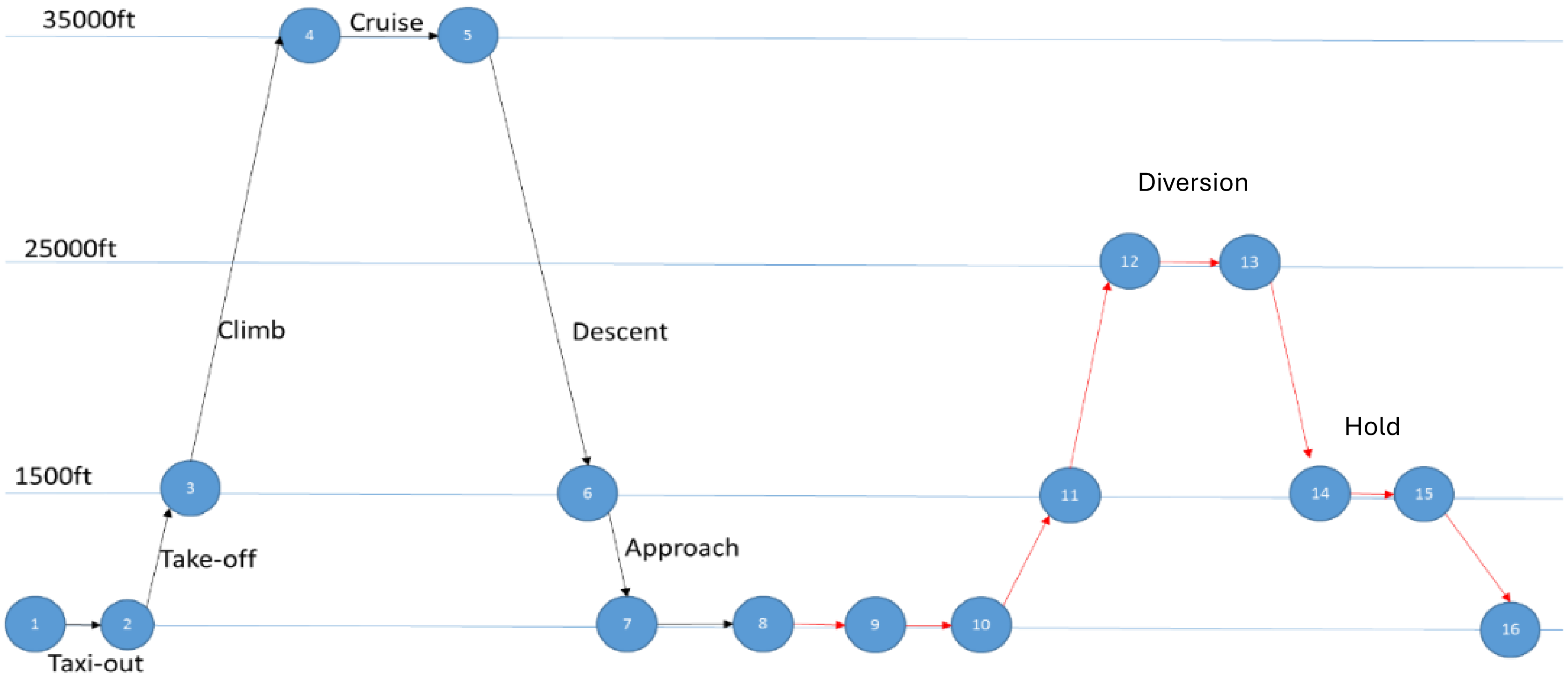
Fixed Wing Performance Tool



Fixed Wing Performance Tool

- In-house **MATLAB** tool created by **Rezgui, Mitchell and Gibbons**.
- Based largely on the reference aircraft in Chapter 10 of **Civil Aircraft Design** by Jenkinson, Simpkin & Rhodes, with a few modification from the Airbus design guides
- To tool generates the aircraft **Payload-Range Diagram** and calculate the **operational performance** for:
  - Given aircraft parameters (configuration, e.g. wing span, engine data, MTOM, empty mass, drag polar, …)
  - Given aircraft mission (Mach number, altitude, required range, payload, …)
- The tool is simple to use and allows flexibility to customise the run files and plotting functions
- Quick start guide available in the form of html and pdf demo files.

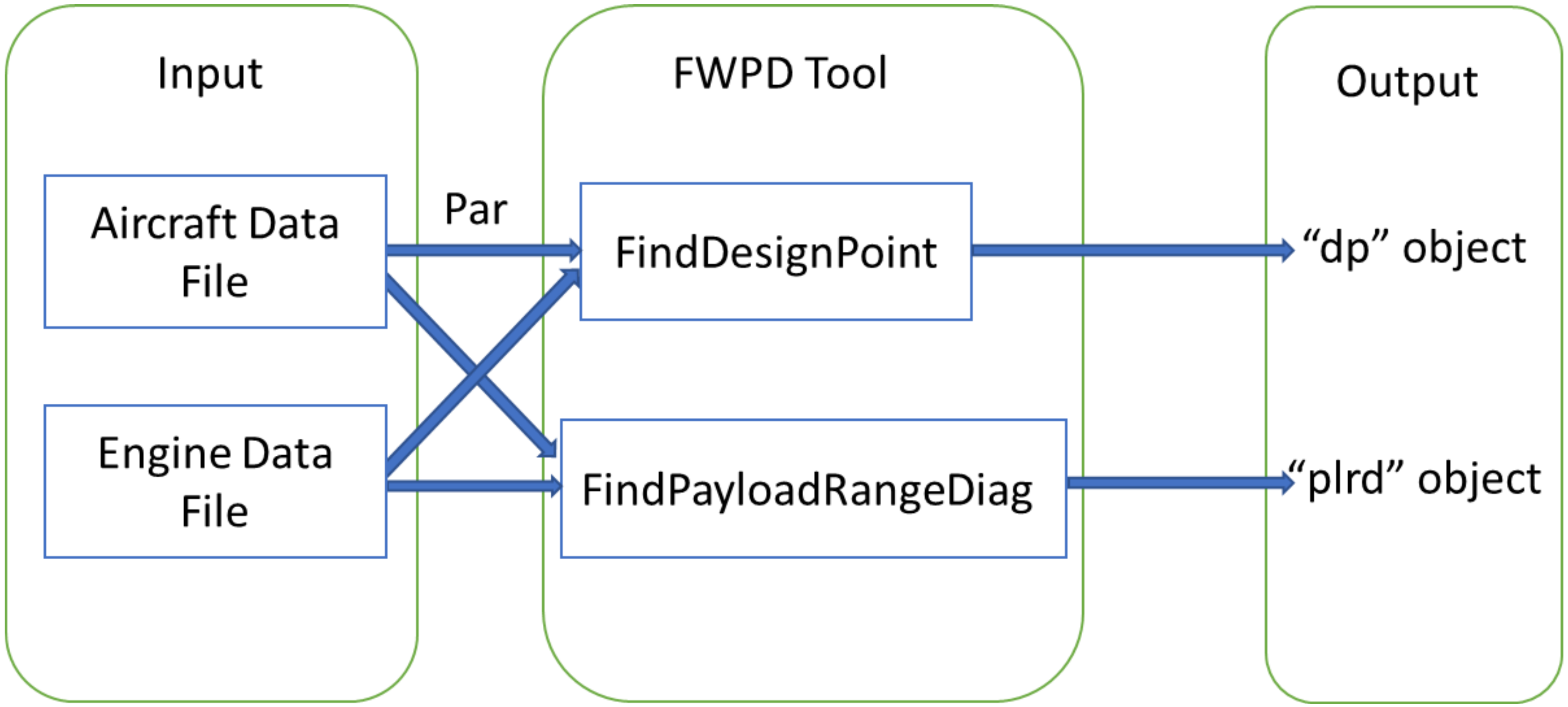
Fixed Wing Performance Tool



Mission Phases

1 - 2	Taxi out	Allowance
2 - 3	Take-off to 1500ft	Allowance
3 - 4	Climb 1500ft to Initial Cruise Altitude	Calculation
4 - 5	Cruise	Calculation
5 - 6	Descent final cruise altitude to 1500 ft.	Calculation
6 - 7	Approach	Allowance
7 - 8	Taxi in	Allowance
9	Overshoot / En route allowance	Allowance
10	Extended Cruise	Calculation
11 - 12	Diversion Climb	Calculation
12 - 13	Diversion Cruise	Calculation
13 - 14	Diversion Descent	Calculation
14 - 15	Diversion Hold	Allowance
15 - 16	Diversion Approach	Allowance

Code Structure



Function Calls

dp = FindDesignPoint(Par, EngineData, TOM_0)

Input:

Par: Object of aircraft parameters

EngineData: Structure of aircraft engine data [optional]

TOM_0: Initial value for TOM [optional]

Output:

dp: object contains design point (dp) results

Function Calls

plrd = FindPayloadRangeDiag(Par, EngineData, Payload_0)

Par: Object of aircraft parameters

EngineData: Structure of aircraft engine data [optional]

Payload_0: Initial value for payload [optional]

Output:

plrd: object contains design point (dp) results

Plotting

Plot mission:

```
PlotMission(dp.Mission)
```

Plot payload range diagram:

```
PlotPLRD(plrd, marker)
```

Marker: line colour and shape [optional]

Run files

- RunDesignCase
- RunDesignSet
- RunPayloadRange

Lab Tasks

- Produce the Payload Range diagram for a notional 1990's twin engine, Airliner *.
- Show how the range at the "design case" varies with different cruise Mach Numbers & Cruise Altitudes.
- Compare the block fuel & block time at a series of ranges (e.g. London to Beijing 4461 nm plus other ranges) for variations in Cruise Mach Number & altitude.
- Carry out trade studies on the effect on block fuel at a fixed range for changes in OME, Drag & SFC.

* Based largely on the reference aircraft in Chapter 10 of Civil Aircraft Design by Jenkinson, Simpkin & Rhodes.

Getting Started with FW Performance Tool

- Watch video on use of MATLAB tool
- Download tool from Blackboard
- Go through Quick Start-up Guide (run files and help documents)
- Attempt the tutorial tasks
- Attend labs for the FW Performance design exercise