Aerospace Vehicle Design And System Integration 3

CADE30007

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

Aircraft Performance

Lecture 1

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Overview

- A brief overview of the course
- Introduction to aircraft performance
- Basic concepts of performance for civil transport aircraft

Learning Outcomes

- On successful completion of this unit, students will be able to:
  - discuss design considerations and describe essential features of aircraft propulsion systems;
  - perform calculations on aircraft propulsion systems, **and fixed/rotary wing aircraft performance;**
  - evaluate implications of various economic, environmental and other operational considerations;

Overview and objectives

- **Objectives:**
  - Advance understanding of general aircraft performance, from what was covered in year 1.
  - Explore the aircraft performance, using dedicated modelling methods for fixed-wing aircraft and rotorcraft.

- **How to engage with the course:**
  - Lecture slides
  - Synchronous lectures
  - Computer labs/tools/exercises
  - Drop in session
  - Discussion board

What is aircraft performance?

- The performance of an aircraft is a statement of its capabilities.
- These capabilities specified for various categories, such transport, military, light aircraft … for both fixed and rotary wing aircraft.
- Aircraft performance is measured for specific design missions:
  - **Fixed-wing aircraft:** civil transportation, private/business transportation, cargo transportation, Fire-fighting, refuelling, military missions …
  - **Rotorcraft:** Civil/cargo transportation, off-shore/business/private transportation, Helicopter emergency medical services (HEMS), Public service (Search and Rescue, law enforcement, military missions …

Aircraft Performance Quantities

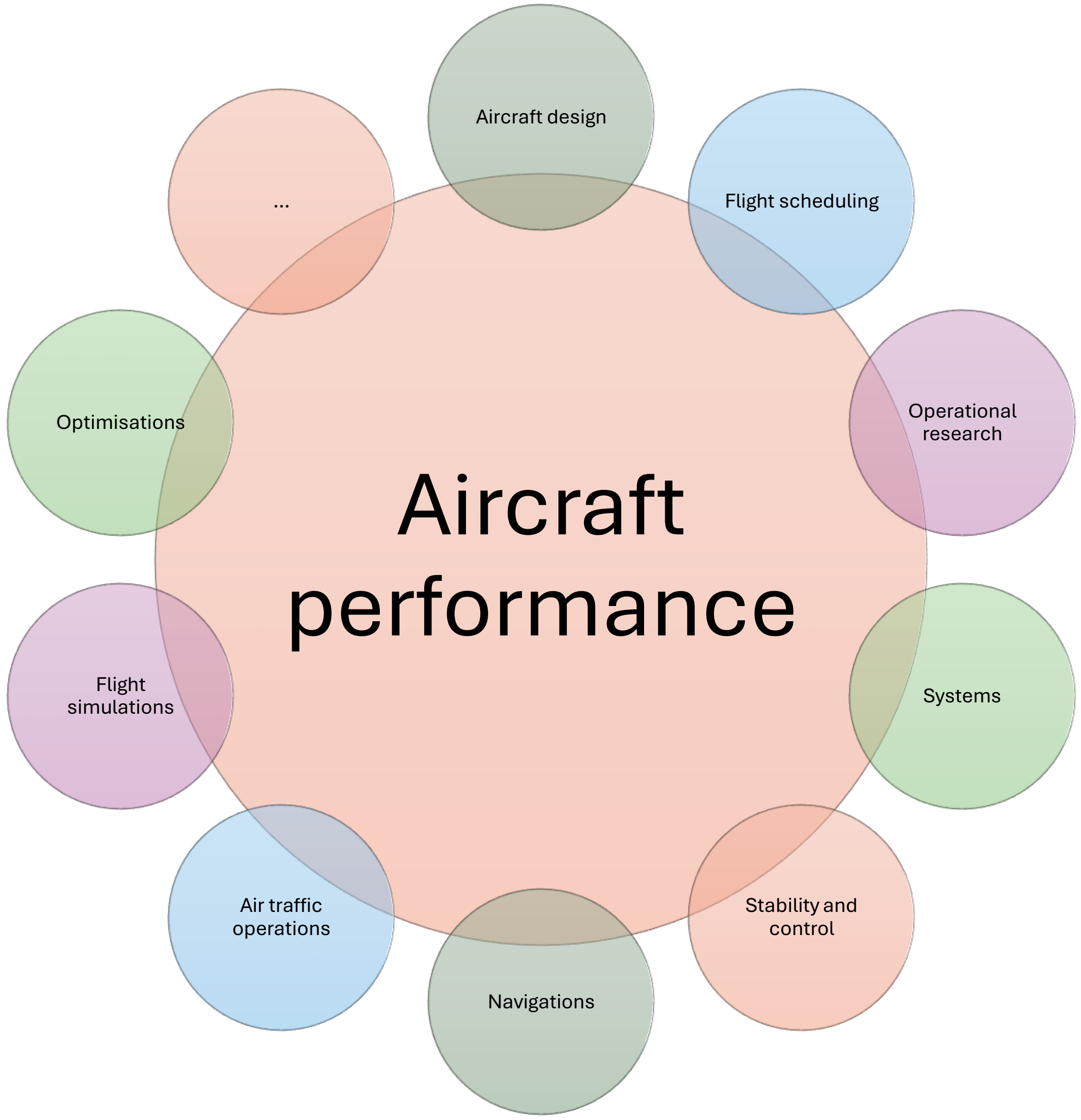
- The performance is stated in terms of quantities such as:
  - Direct Operating Cost (DOC)
  - Maximum range for various payloads and fuel loads
  - Cruising speed, aircraft manoeuvrability, altitude ceiling …
  - Airport requirements for landing and take-off
  - Aircraft noise and emissions
  - Engine failure performance

Why do we need to evaluate the aircraft performance?

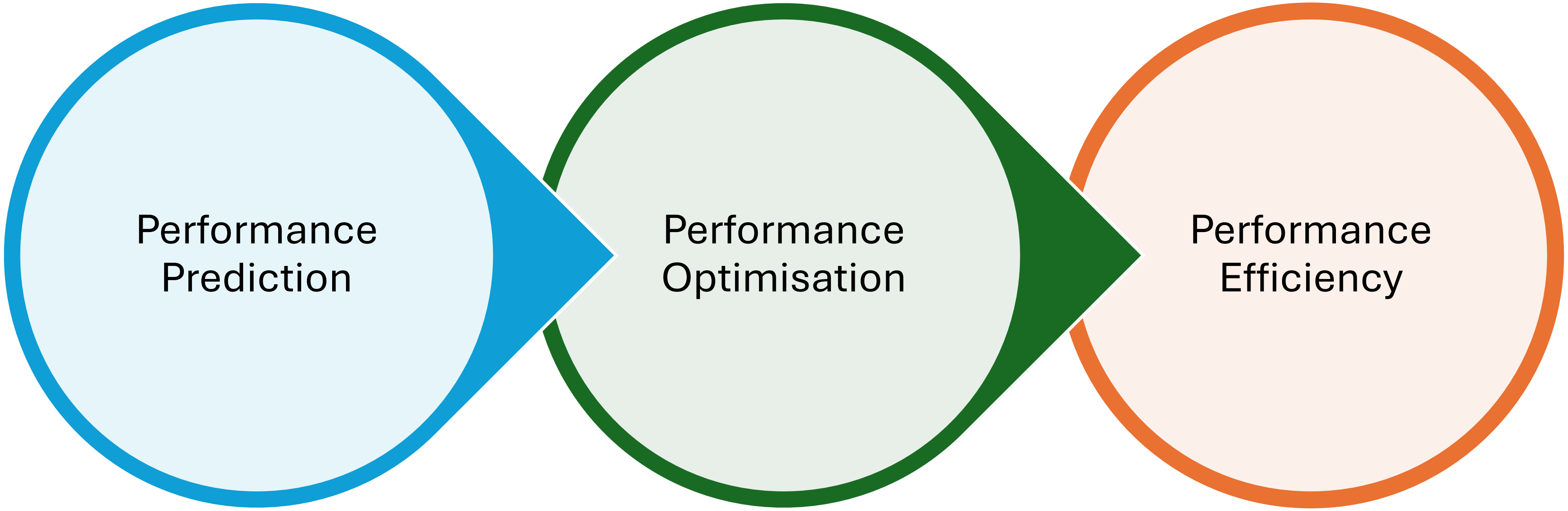
- Design of new aircraft
- Select a new aircraft
- Verify that the aircraft achieves its design targets
- Efficiently operate an existing aircraft or fleet
- Modify, upgrade and extend the flight envelope
- Upgrade and extend the mission profile
- Investigate the cause of aircraft accidents
- Provide data for aircraft certification
- Environmental analysis on the ground and in-flight

In general, the subject of aircraft performance intersects with several other disciplines:

- Aircraft performance:
  - Aircraft design
  - Flight scheduling
  - Operational research
  - Systems
  - Stability and control
  - Navigations
  - Air traffic operations
  - Flight simulations
  - Optimisations
  - …



Performance analysis

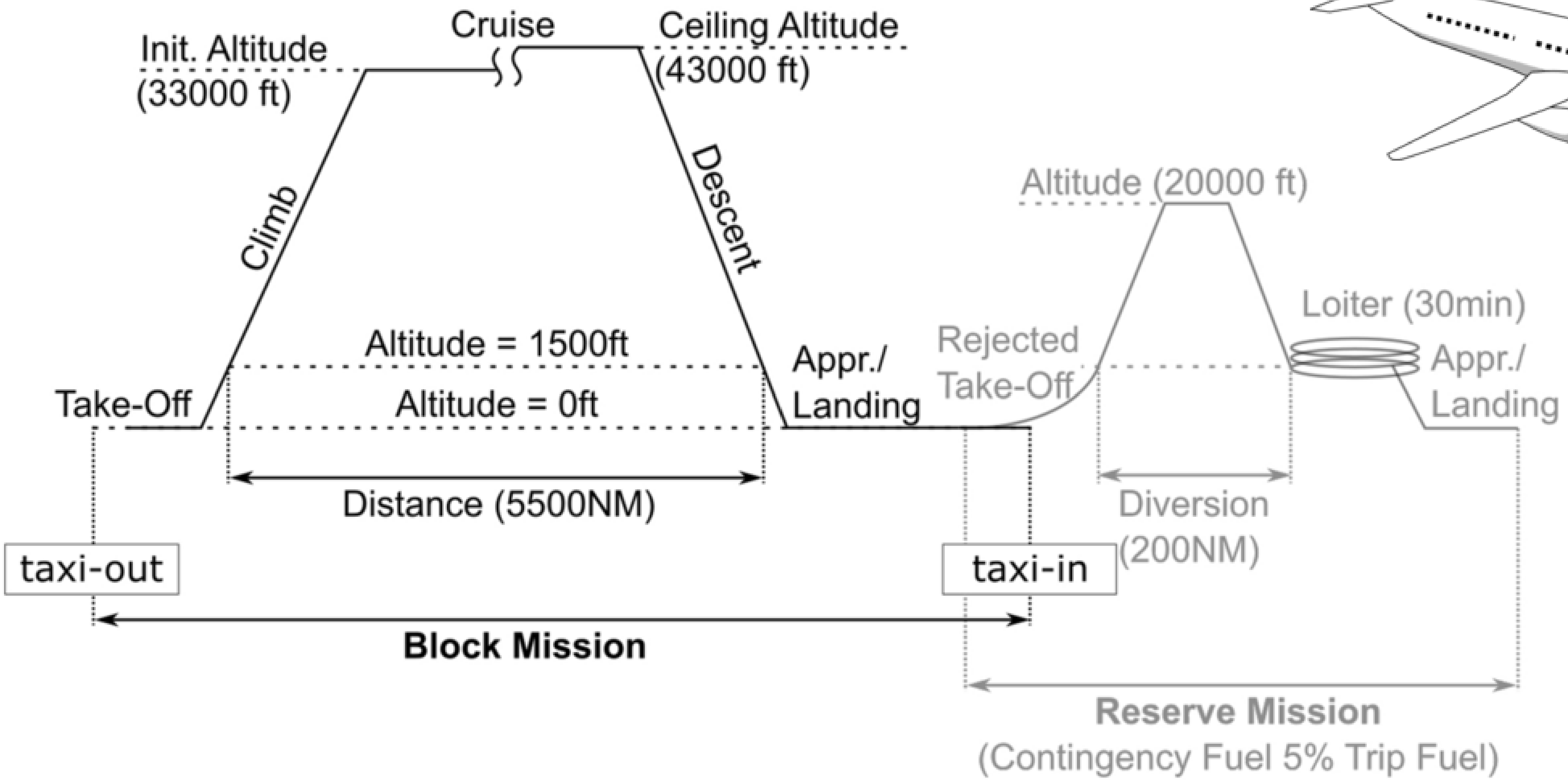


Performance parameters

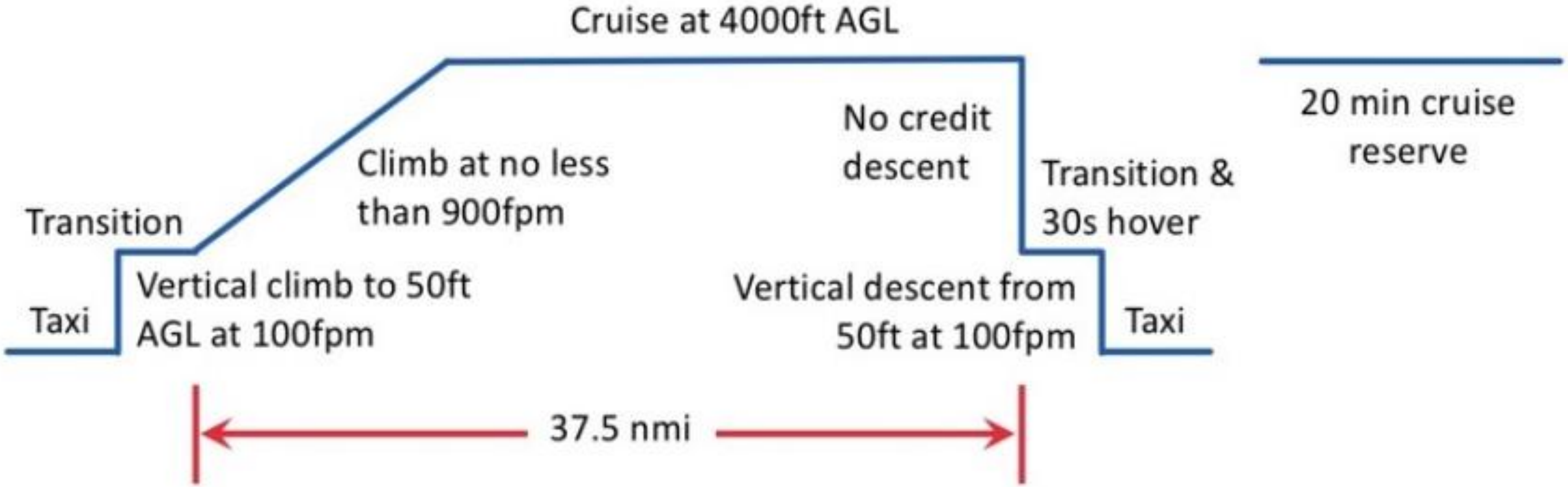
Performance parameters are quantitative indicators representing how a vehicle operate in a flight condition:

- Weights, including payload, fuel load …
- Speeds, Mach numbers, rates of climb/descent …
- Aerodynamic loads
- Engine thrust and power
- Fuel consumptions, engine status …
- Range and endurance
- Aircraft attitude: accelerations, flight path angle, angular velocities …
- Altitude, air temperature …
- Emission indices (noise, exhaust gases …)
- Many more … at least 60 or so parameters can be considered in a full aircraft performance analysis

Aircraft mission profiles (transport)



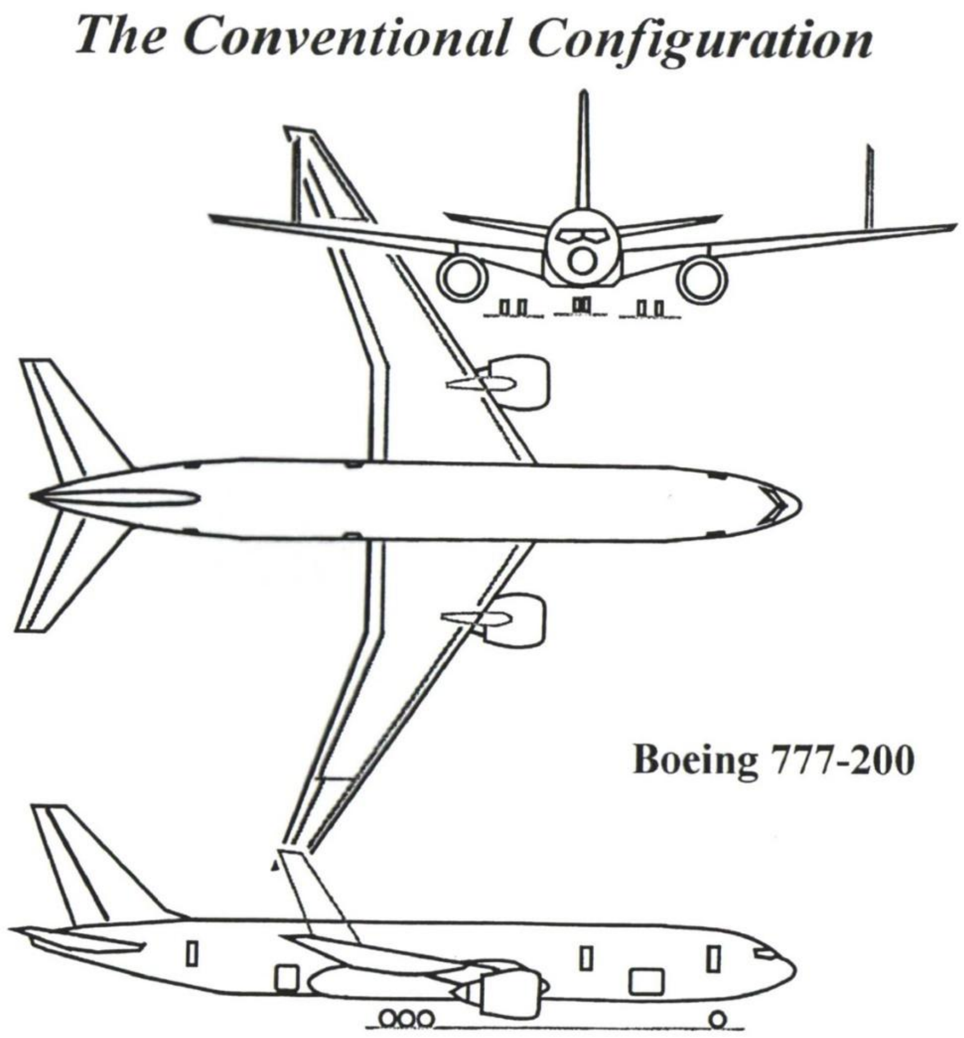
Helicopter mission profiles



AGL: Above Ground Level

Performance of Civil Airliners

Design Case



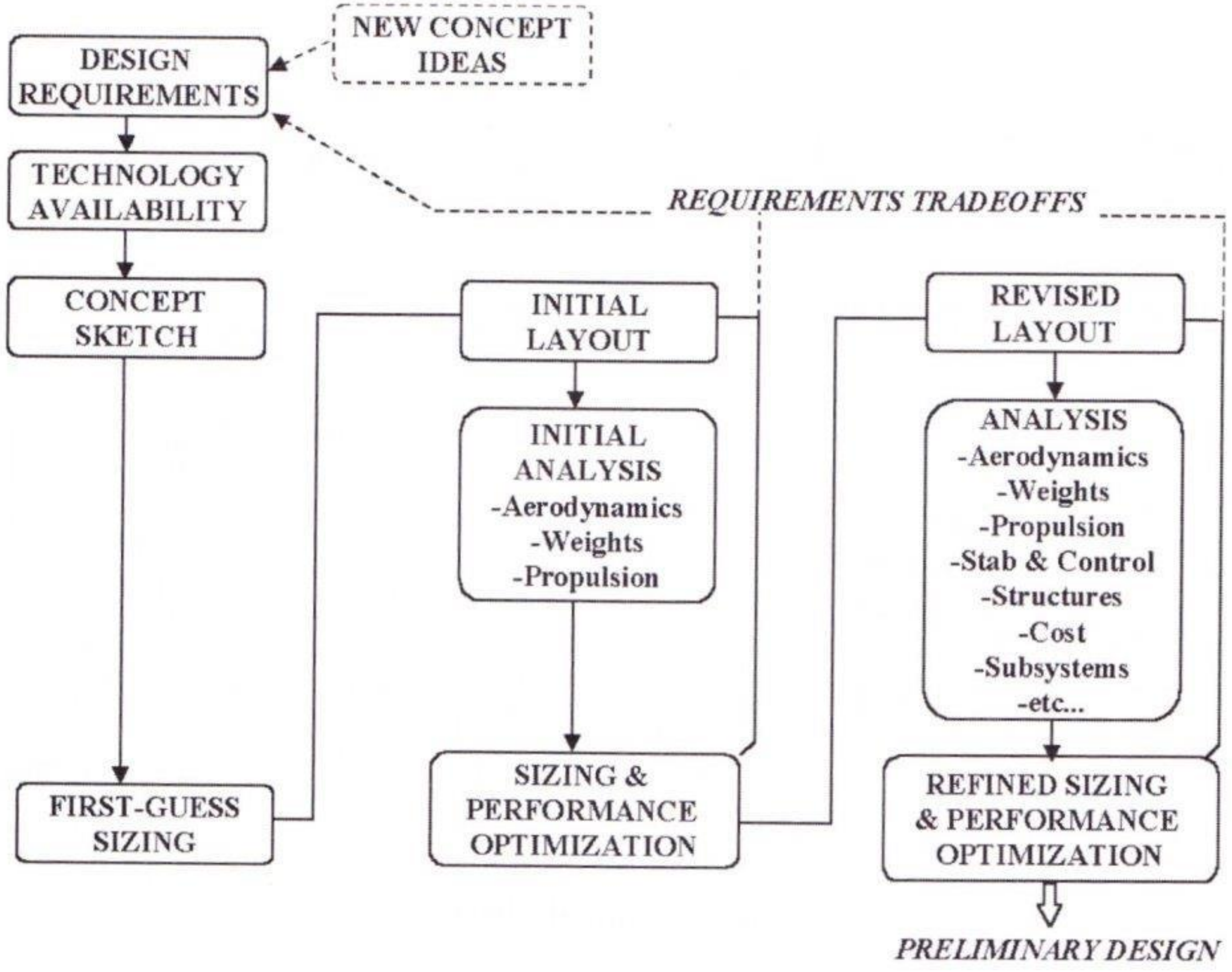
Choice of Characteristics in the Preliminary Design of a Transport Aircraft

The Preliminary Design Process

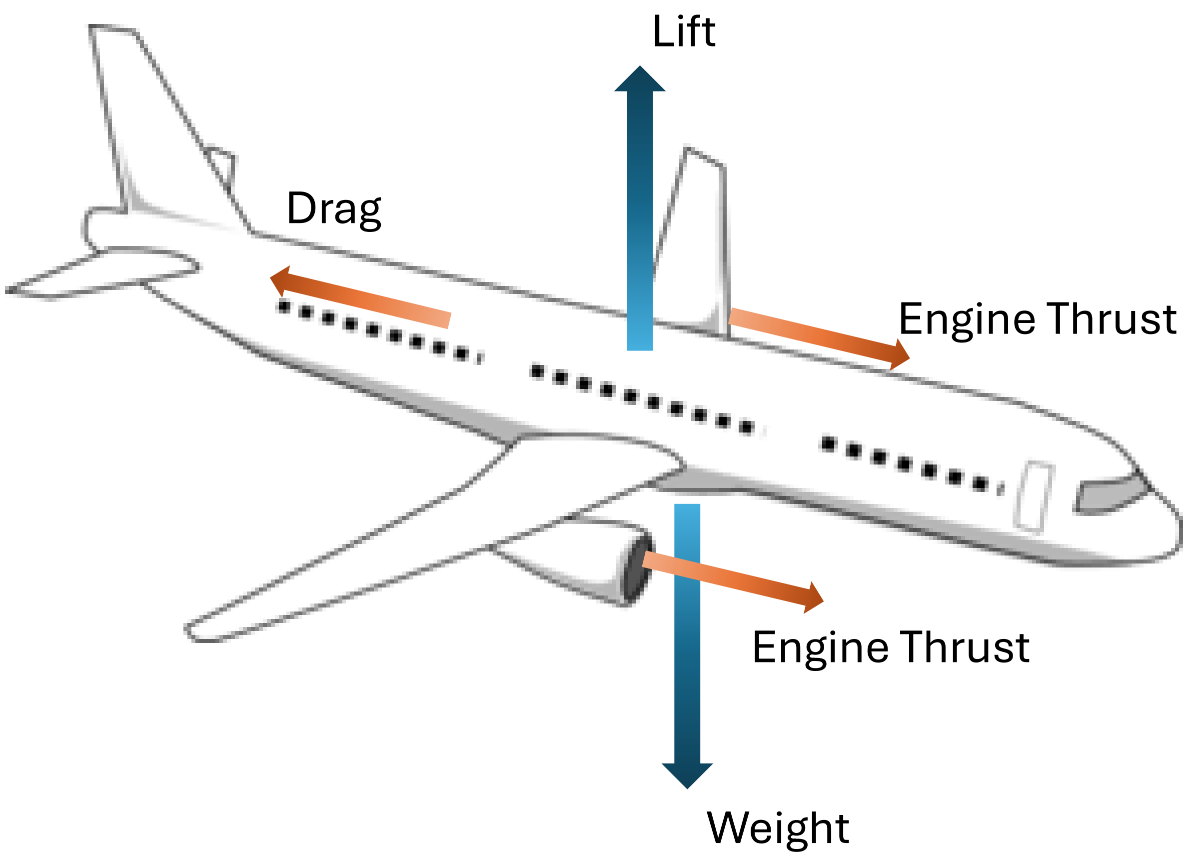
- The purpose of the Preliminary Design Process is to produce a viable aircraft design which meets the following criteria:
  - *Meets the Aircraft Specification i.e. will fly the design range with the design payload & at take-off & land at nominated airfields;*
  - *In addition, it must be able to operate & manoeuvre safely over the specified flight envelope;*
  - *Meet all environmental & safety requirements as laid down by the certifying bodies.*
- The "best" design is usually the one that meets all of the above using the minimum amount of fuel for the specified mission;
- The aircraft's structure, drag and engine size (and hence fuel burn) are all a first or second order function of the take-off mass.
- Generally, this means that the aircraft take-off mass should be minimised.

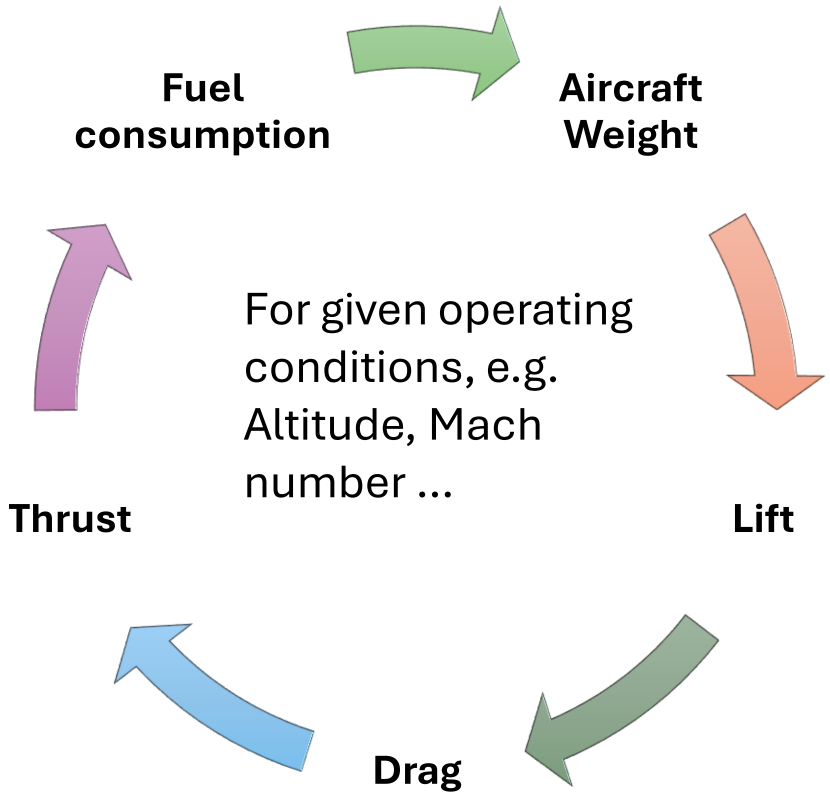
The Preliminary Design Process

Reference: Aircraft Design : A Conceptual Approach D P Raymer



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

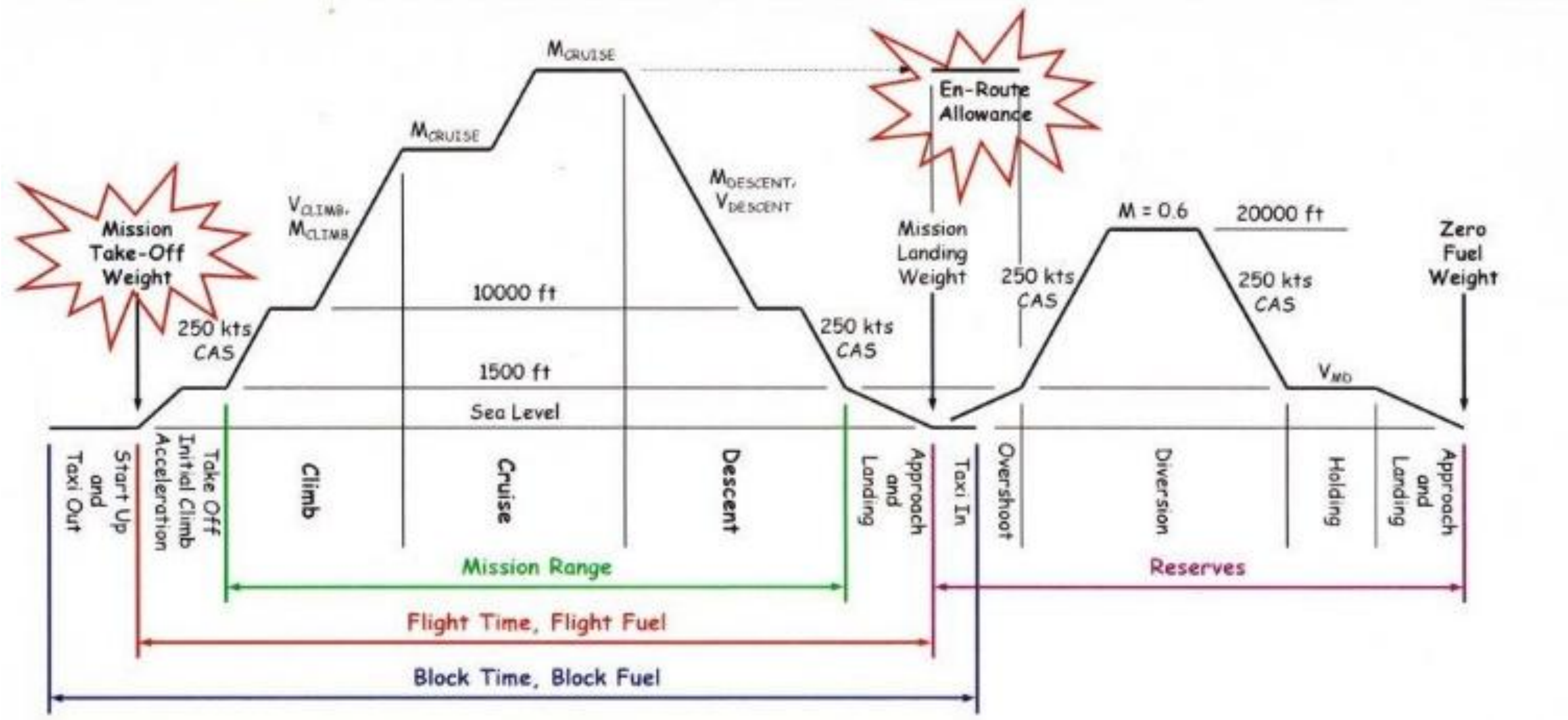
“Wave Drag”

Drag due to Reynolds Number

Engine Data

Thrust & Fuel Flow across the Flight Envelope

Typical Mission Profile for a Civil Airliner



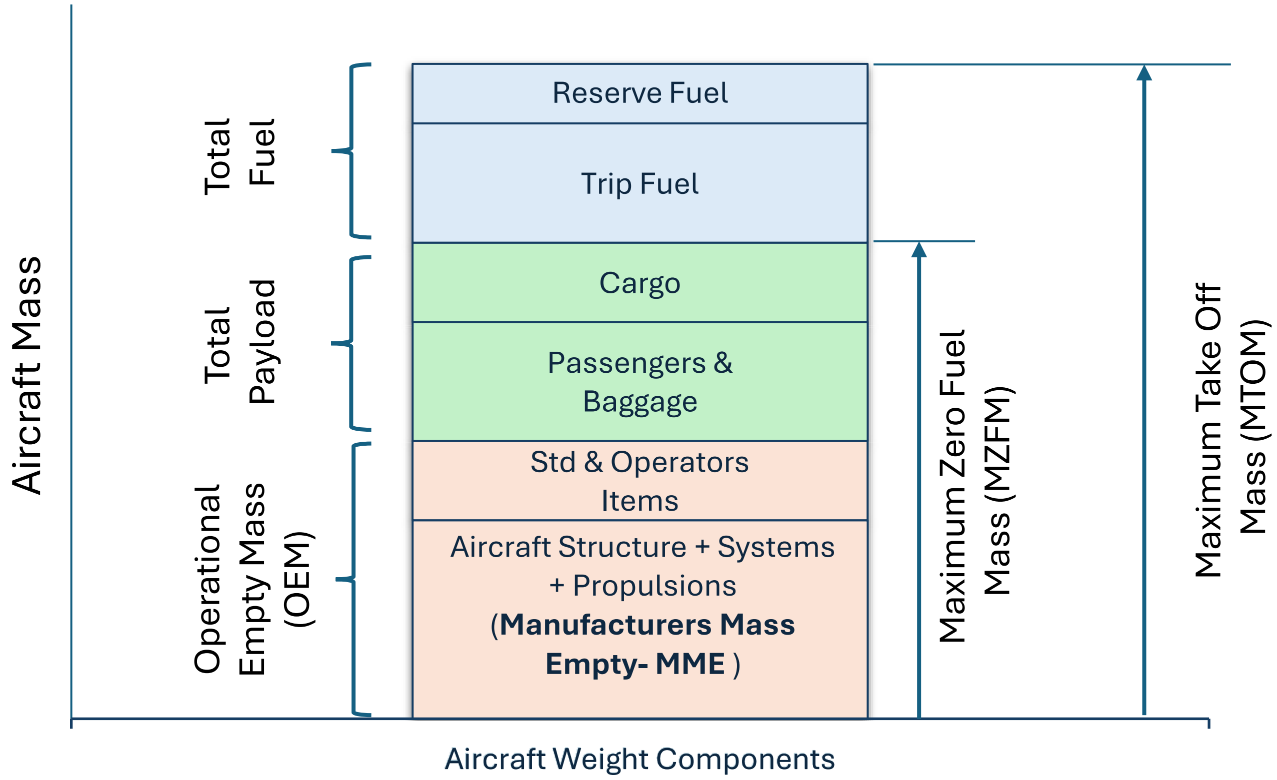
Mission Phases

Taxi out	***7 minutes at ground idle fuel flow or a fixed mass of fuel.***
Take-off to 1500ft	***2 minutes at SLS Take off fuel flow or a fixed mass of fuel.***
Climb to cruise altitude	
Cruise	
Descend to 1500 ft	
Approach	***5 minutes at Approach Speed & Thrust or a fixed mass of*** *fuel.*
Taxi in	***7 minutes at ground idle fuel flow or a fixed mass of fuel.***
Overshoot	***Typically 80% of Take-off to 1500 ft***
Diversion	X miles at best range speed & altitude (typically 200 nm)
Diversion Approach	***As approach***
En route allowance	X minutes of cruise extended cruise or 5 % of cruise fuel.

Fixed Allowances - not generally part of an iteration

Note times may vary with different specifications.

Aircraft Mass (Weight) Breakdown



Aircraft mass breakdown in one trip:

$$Mass_{final} = Mass_{initial} - \text{Trip Fuel}$$

$$Mass_{final} = \text{OEM} + \text{Payload} + \text{Reserve Fuel}$$

Aircraft Mass Definitions

MME	**Manufacturers Mass Empty** = Mass of aircraft as delivered by manufacturer (without operator items installed)
OME (OEM)	**Operators Mass Empty =** MME + operator items necessary for aircraft service, i.e. interior furnishings (galleys, seats, lavatories, entertainment systems), crew (flight deck and cabin attendants), unusable or trapped fuel
MLM	**Maximum Landing Mass =** Maximum mass at which aircraft can land safely
MZFM	**Max Zero Fuel Mass =** OME + passengers + baggage
MTOM*	**Max Take-off Mass =** MZFM + full fuel * Maximum cleared mass for take-off i.e. **Design Case**
MRM	**Max Ramp Mass =** MTOM + Taxi Fuel
Design Payload	Payload at Design Range
Max Payload	Maximum Payload
Max Fuel Capacity	Maximum Fuel Load

Trip Range - Breguet-Range equation

$$R = \frac{a}{g * tsfc}\left(M\frac{L}{D}\right)\ln\frac{Mass_{initial}}{Mass_{final}}$$

$$R = \frac{V}{sfc}\left(\frac{L}{D}\right)\ln\frac{Mass_{initial}}{Mass_{final}}$$

The Breguet Range Equation gives the range of an aircraft as a function of:

- Altitude through sound speed (a), and ($tsfc$) (thrust specific fuel consumption)
- Engine efficiency, through ($tsfc$)
- Aerodynamic efficiency, through $M\frac{L}{D}$
- Structural efficiency through ($\frac{Mass_{initial}}{Mass_{final}}$)

Cruise Speed & Initial Cruise Altitude

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

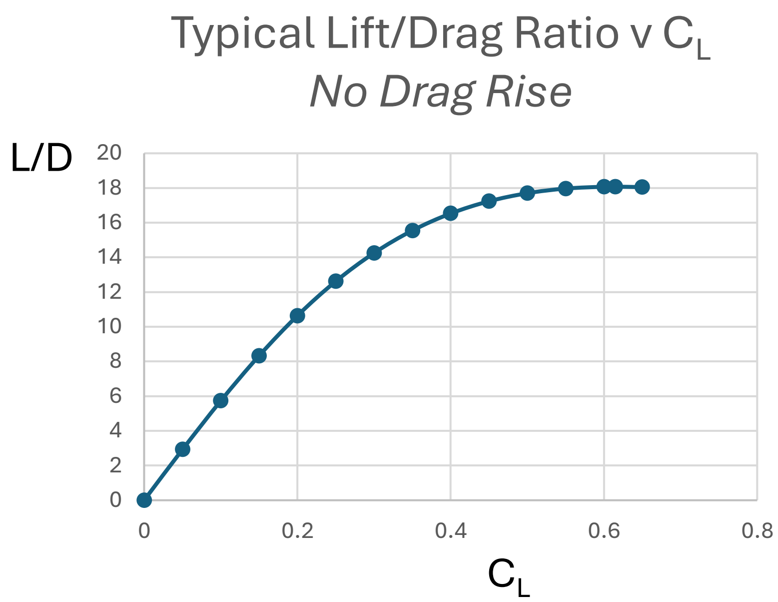
- **Long Range Aircraft Twin Aisle (250 – 500 + seats) Range 5000 nm +**
  - *Long Range Cruise Speed M = 0.83 – 0.85 ICA at least 35,000 ft*
- **Medium Range Single Aisle (150 - 250 seats) Range 3000 nm**
  - *Long Range Cruise Speed M = 0.76 – 0.80, ICA at least 35,000 ft*
- **Short Range Turbofan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

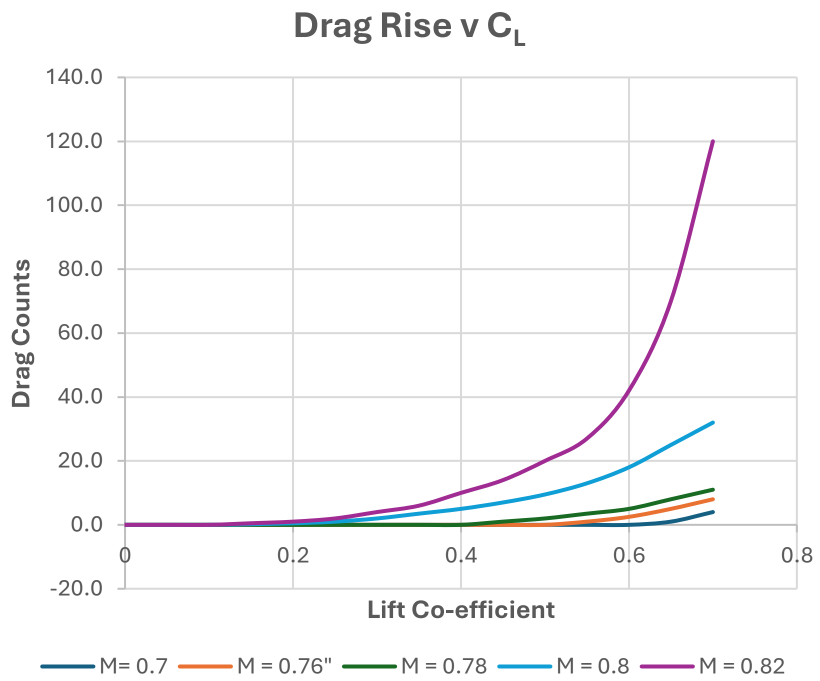
Generic Drag Characteristics

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

- C_{DTot} = Total Drag Co-efficient
- C_{Do} = Zero Lift Drag at a Reference Reynolds Number
- K = Induced Drag Factor
- C_L = Lift Coefficient
- $\Delta\, C_{Dw}$ = Increment in drag due to shock wave effects a function of C_L & Mach Number
- $\Delta\, C_{DRe}$ = Increment in Drag due to difference in R_e from Reference R_e
- *Note for the exercises in AVDASI 3, the $\Delta\, C_{DRe}$ can be ignored.*

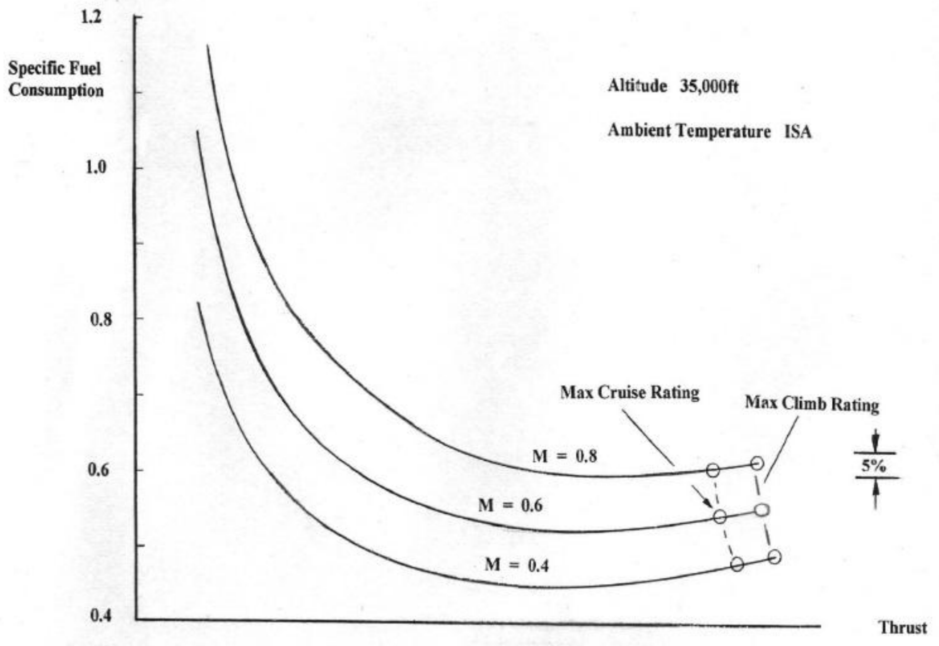
Note: One Drag Count = 0.0001

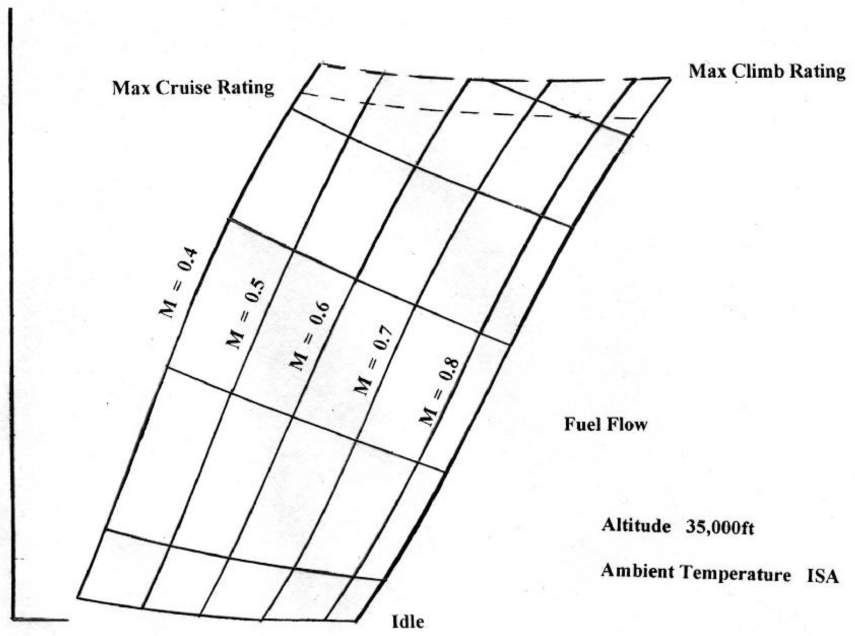




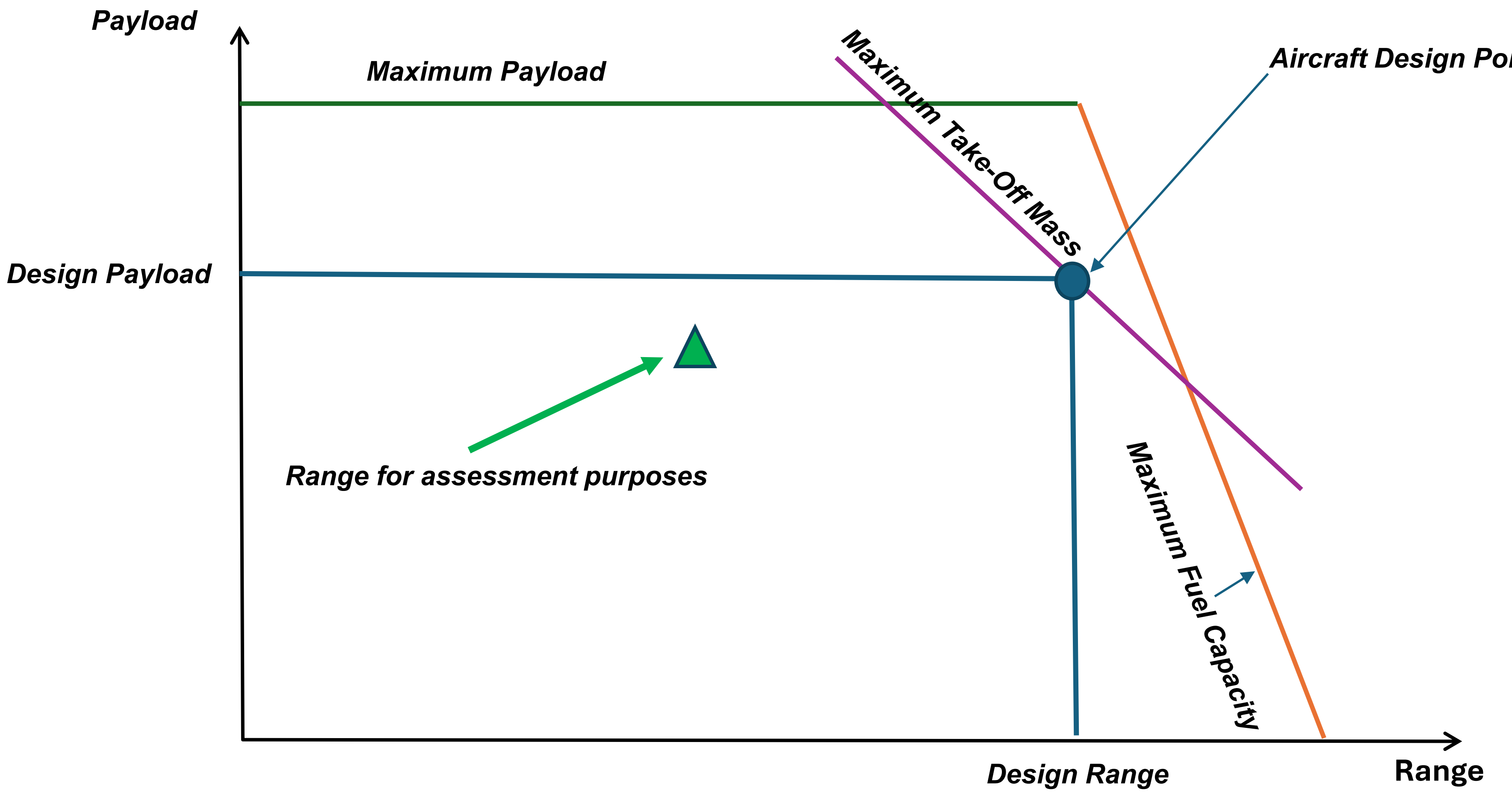
Engine Data

- The data is in tabulated form of thrust v specific fuel consumption or fuel flow at intervals of Mach Number and altitude.
- The data will cover a range of “throttle settings” from the minimum sustainable (flight idle RC 20) to a maximum cruise (RC 35) & maximum climb (RC 40) rating.
- Thrust v fuel flow can be interpolated linearly.

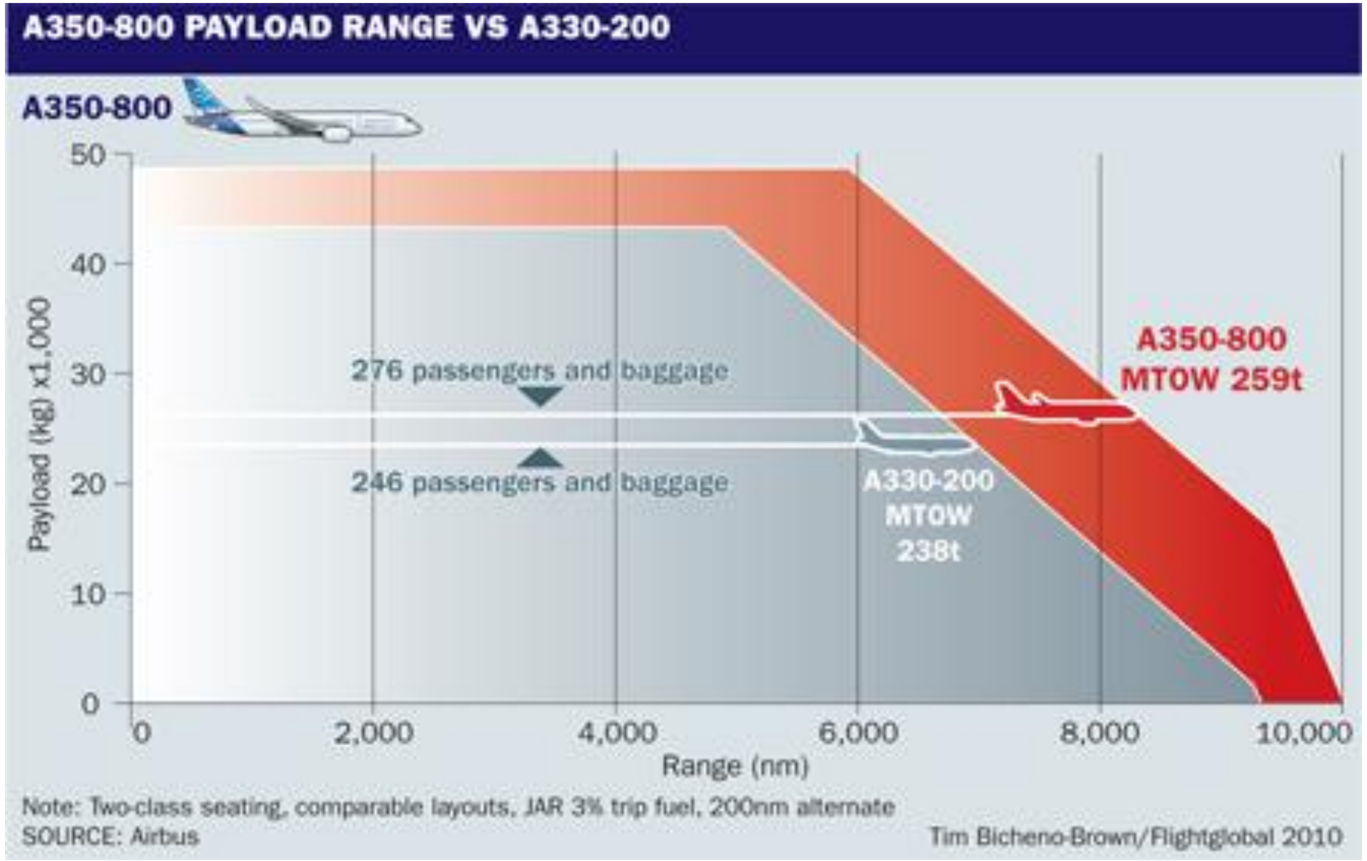


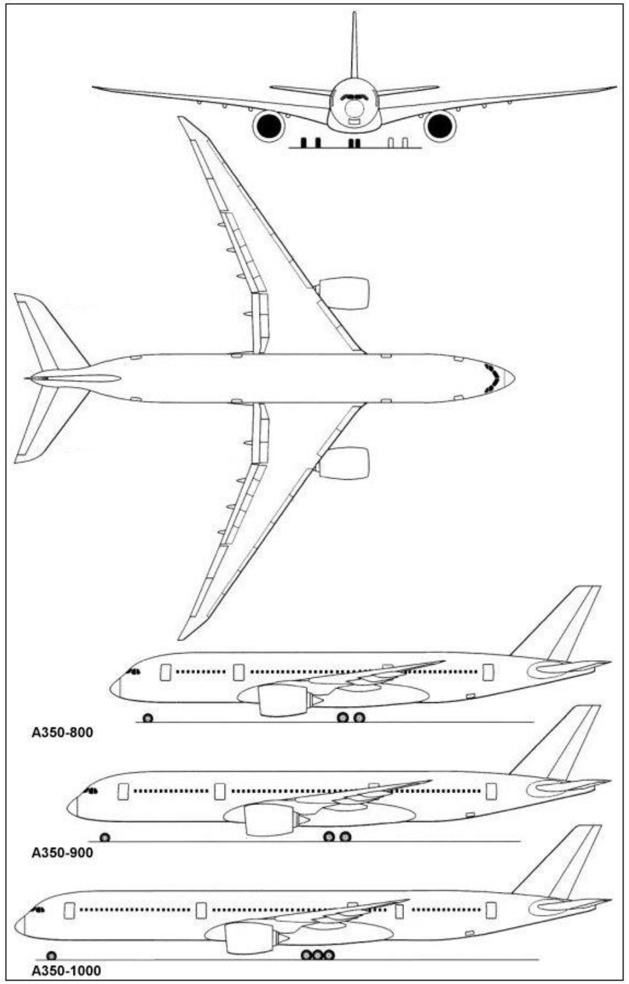


Payload Range Diagram



Payload range diagram





Questions