IB Elective

Aerothermal Engineering

Design of a Jet Engine

for a

600-Seat Aircraft

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Nominally 14 lectures and 2 example classes (16 sessions at 4 per week)

Course structure:

Majority of notes and exercises are in the booklet handed out.

Additional material will be provided in the lectures.

The course is evolving: (since October 2005)

Sections 9.4 & 9.5 and Chapter 10 in booklet are no longer part of the course.

Some of the earlier material has been expanded.

You should work through the booklet as the lecture course progresses.

(Solutions to exercises will be made available.)

Lectures will be more flexible – talk on issues of interest, background etc. Lectures will talk on topics roughly in synchronisation with where you should be in the notes.

Recommended reading (optional):

In addition to the booklet you may wish to read further about jet engine design:

N.A. CUMPSTY, “JET PROPULSION”, Cambridge University Press 2nd edition, 2003, VN47 (The basis of the course booklet with some additional material)

P.G. HILL & C.R. PETERSON, “MECHANICS AND THERMODYNAMICS OF PROPULSION”, Addison-Wesley 2nd edition 1992, VN41 (A very good introduction)

ROLLS ROYCE, “THE JET ENGINE”, Rolls Royce 5th edition 2005, VN48 (Excellent practical background with some great pictures)

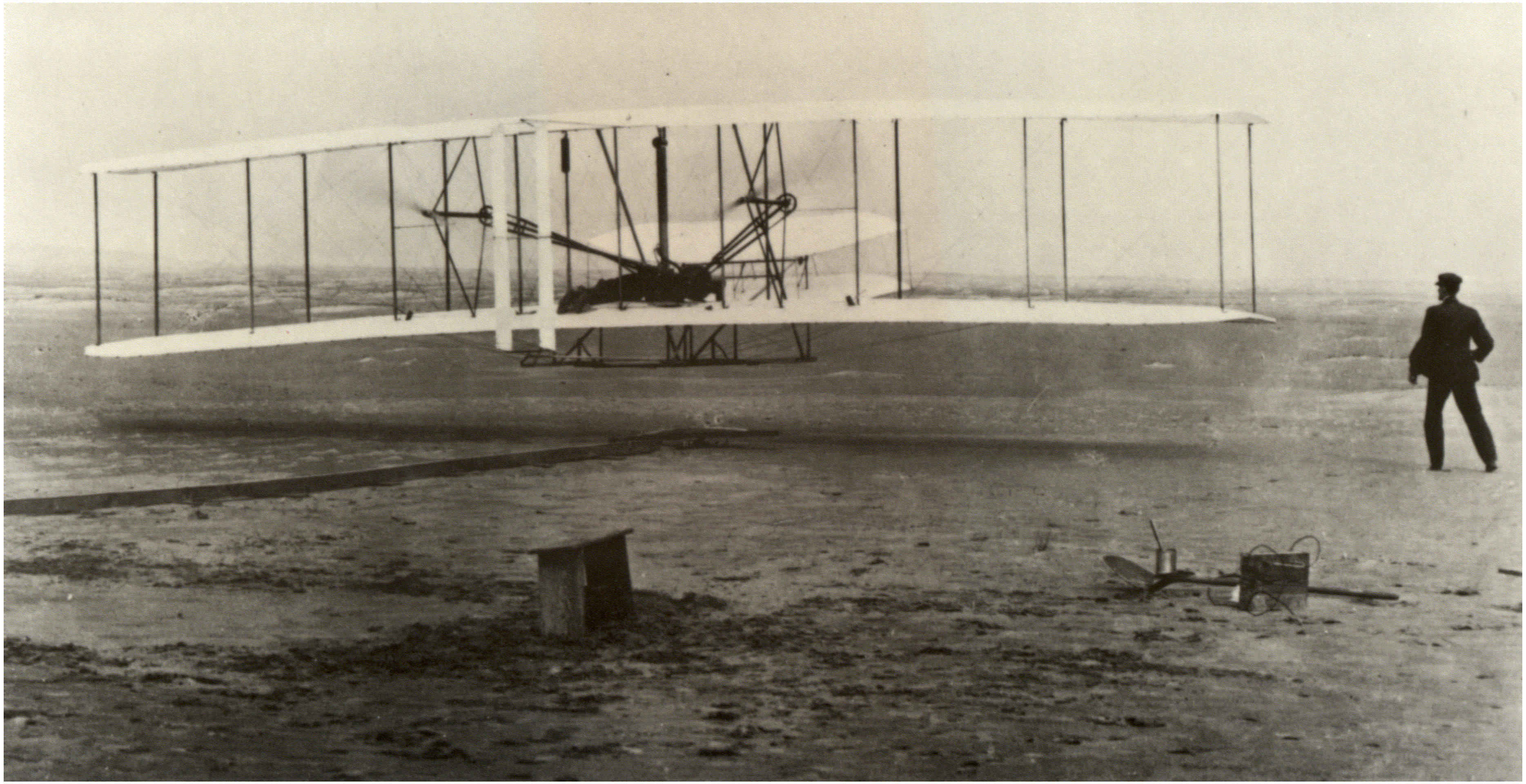
H. COHEN, G.F.C. ROGERS & H.I.H. SARAVANAMUTTO, “GAS TURBINE THEORY”, Longman 4th edition 1996, VK 34 (Details on jet engine turbomachinery)

Course overview:

Part 1
- History of aviation and aircraft propulsion.
- Design specification for a new large aircraft (aka Airbus A380).
- Flight envelope and engine thrust requirements (take-off, top-of-climb, cruise).
- Aircraft fuel consumption and measures of jet engine efficiency.
- Aeroengine layout.

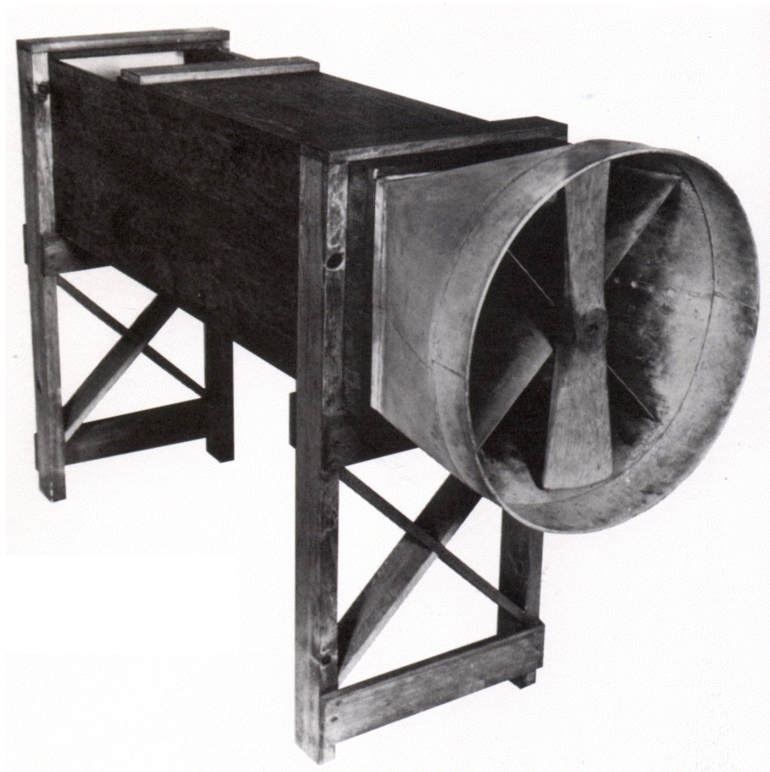
Part 2
- Compressible flow (choked nozzle).
- Selection of bypass ratio (choice of fan diameter).
- Non-dimensional scaling of performance (take-off, engine-out).
- Basic turbomachinery design (number of stages and size).

The First Flight (10:35 am, December 17th 1903, 120 feet, 12 seconds)



The lecturer, Orville and Wilbur Wright

The Wright Brothers' wind tunnel



The role of the jet engine:

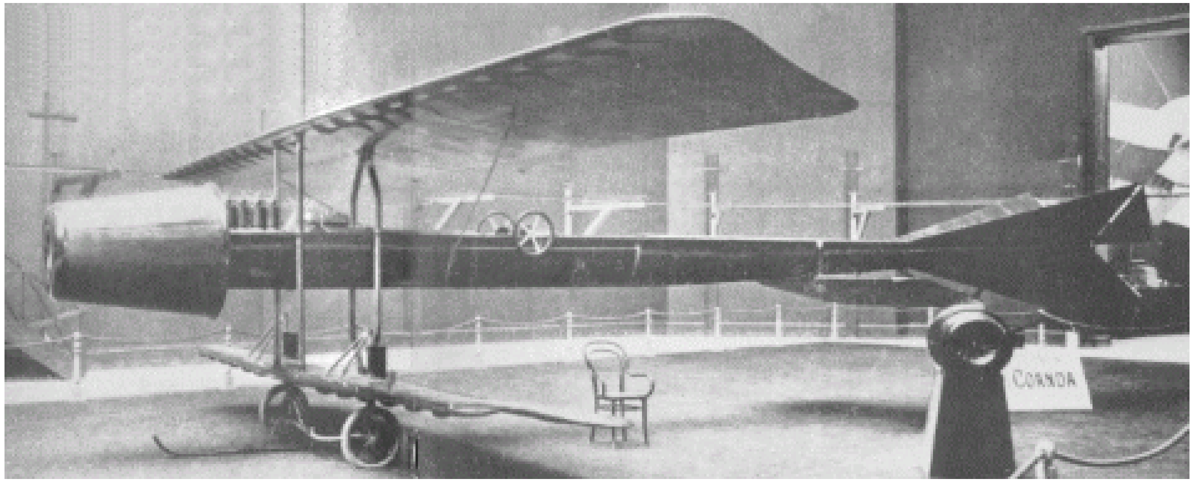
The development of the jet engine enabled the greatest revolution in aviation since the Wright brothers' first flight.

Before 1939 aircraft used piston-engine powered propellers for propulsion. Their performance was limited by propeller efficiency, which falls rapidly once the blade tips become supersonic.

Jet propulsion had been considered. In 1923, Edgar Buckingham of the US National Bureau of Standards published a report stating:

"…there does not appear to be, at present, any prospect whatsoever that jet propulsion will ever be of practical value..."

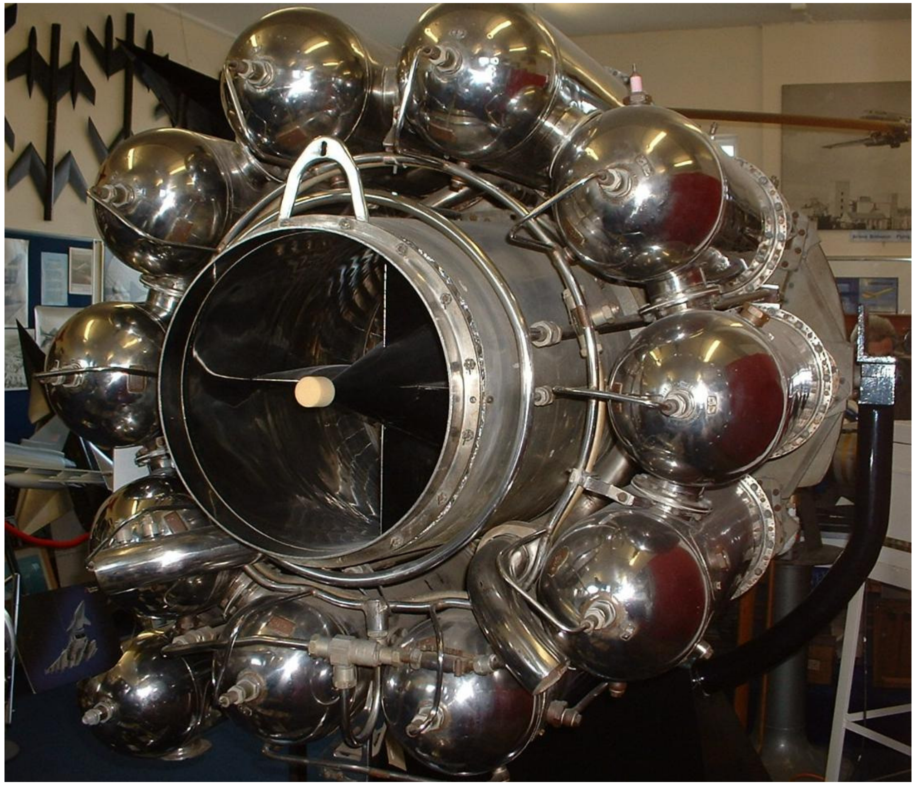
Some early attempts were made using “hybrid” engines in which a piston engine drove a compressor to create a propulsive jet…



The Coandă-1910: the first jet-propelled aircraft, built by Romanian inventor Henri Coandă and exhibited in Paris around October 1910.

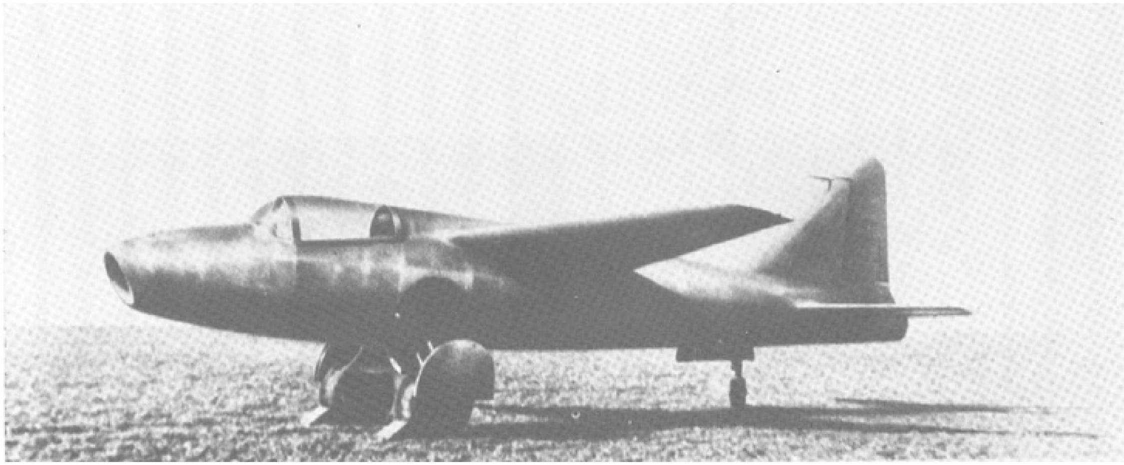
However, the key to a practical jet engine was the use of a gas turbine in which the power output from the turbine is used to drive the compressor.

On 16 January 1930, Frank Whittle submitted his patent for a turbo-jet. His engine first ran in 1937 but development was severely hampered by a lack of government support.



The Whittle W.2/700 engine used to power the Gloster E.28/39, the first British aircraft to fly with a turbojet engine in May 1941.

Independently of Frank Whittle, Hans von Ohain started work on a similar design in Germany, which led to the first turbojet powered aircraft:



The Henkel He 178. Its first flight was on 27 August 1939

Rapid developments in turbojet engine technology followed (axial compressors, improved materials, advanced bearings, etc.)

In the 1970s the high bypass ratio engine entered service allowing greater propulsive efficiency at high flight speeds. This has led to today´s fast, safe and economical system of global air travel. However, there are new challenges…

Requirements for new and future aircraft:

Exceptional safety (enforced through regulation and certification requirements)

High revenue potential (high payload, maximum utilisation, high reliability)

Low operating costs (low maintenance, high durability, low fuel burn, minimal crew)

Reduced environmental impact (page 12)

- Low local emissions (NO_x, particulates)
- Low noise
- Low Carbon Dioxide emissions (likely to become increasingly important)

These needs are driven by the massive growth in air travel, the highly competitive airline market and the growing concern for the environment.

What are the particular constraints for a new large aircraft?

Must fit in 80 m × 80 m × 80 ft box (80 metre cube!!)

This is the physical size set by airports, hangers and departure ways.

There must be a market for it!

Estimated at 1000 – 1500 airplanes

Airbus currently have 202 orders for 17 customers (Mar 2010)

They have so far delivered 26 (to Singapore, Emirates, Air France, Qantas)

Costs:

A380 project development cost: \$11 billion, \$13 billion, \$17 billion, ….

Purchase cost for one A380 is approximately \$320 million

(Current sales revenue = 202 × \$320 million = \$64.6 billion)

Engine development cost: \$2 to \$3 billion (estimate).

Design Specification for New Large Aircraft (NLA): (Table 1.1 in booklet, page 4)

OUR DESIGN

	New Large Aircraft	Airbus A380-100*
Number of passengers	620	555
Range (nautical miles)	8000	8150
Payload at this range (a)	58.5 tonne	52.9 tonne
Empty weight, no fuel, no payload (b)	298.7 tonne	274.9 tonne
Fuel capacity (c)	275.4 tonne	≈232.4 tonne
Max take-off weight (d ≈ a + b + c)	635.6 tonne	560.2 tonne
Cruise Mach number	0.85	0.85
Initial cruise altitude	31000 ft	35000 ft
Cruise Lift/Drag	20	20
Wing area	790 m^2	845 m^2

Exercises based on these numbers.

*Note that this specification is only slightly different from the A380-800 in production

Comments on the design point for the New Large Aircraft:

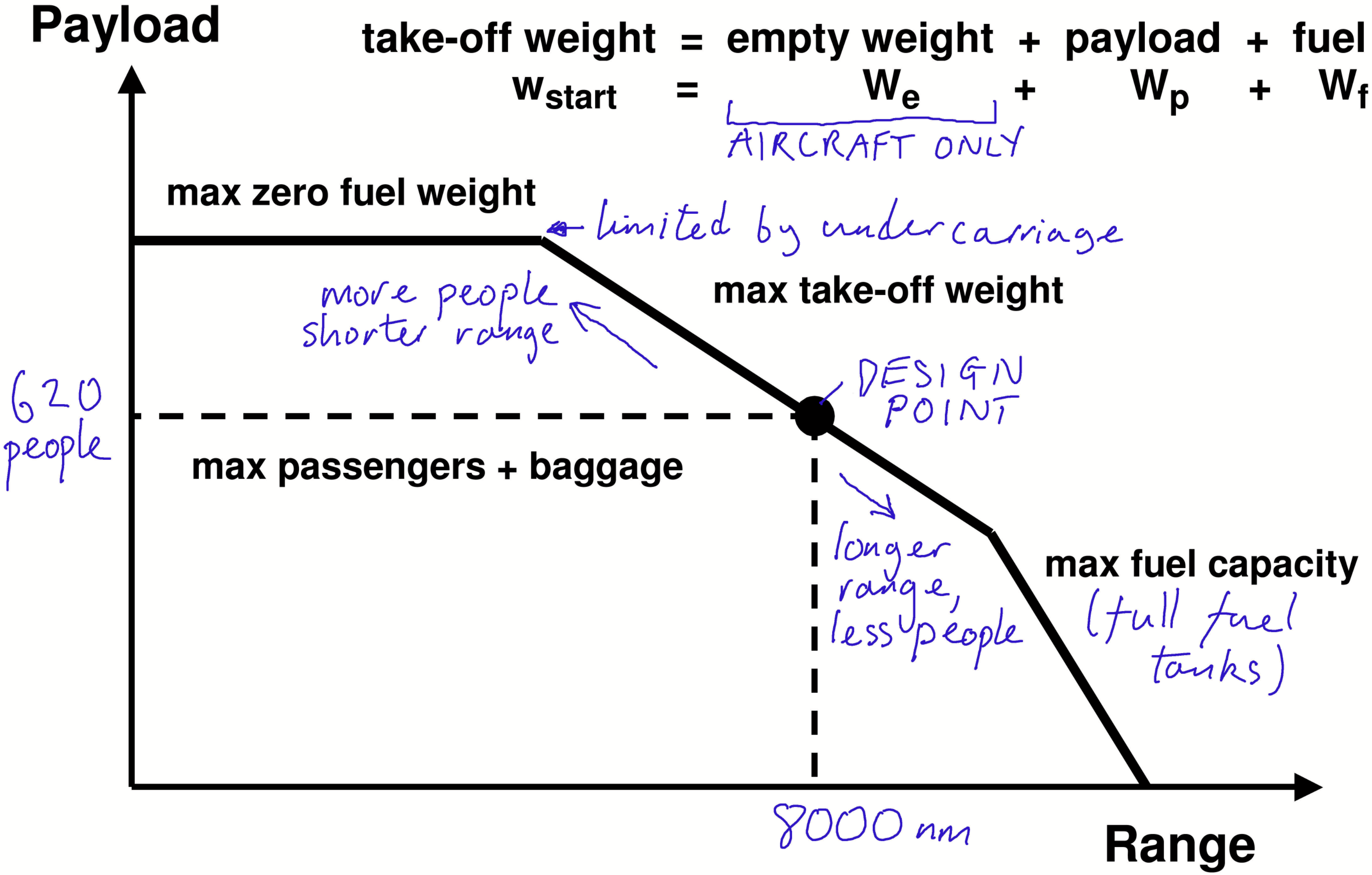
Base our design around the “top-of-climb” flight condition at an altitude of 31000 ft and a speed corresponding to a Mach number of 0.85. (We will discuss later why planes cruise in low density air at high altitude.)

275.4 tonne 58.5 tonne

Note the significance of the weight of fuel, it is about five times the payload.

Payload and Range are linked because fuel is such a large fraction of take-off weight.

Payload Range Diagram for a typical civil Aircraft



How our design range and payload compare with existing fleet: ⊕ NLA (very high range and payload)