1 Air Transport as part of overall traffic

- Air transport: On one hand dismissed as commodity, on the other as as magnet for the population (high interest)
- Economist perspective: Air transport as part of econom. transport system
- Modern economy: Division of labour: Pre-requisite for this is a functioning air transport system
- Air transport is an **indicator of wealth and poverty**
- **Globalisation** builds strongly on air transport
- Strong growth projected (based on CAGR of 3.7% $\rightarrow$ 7.2 billion in 2035 / double of 2016)

Air transport vs. Aviation

- **Air traffic/transport**: All operations used to change location of people, freight and post by air and incorporates all services directly associated with the change of location (flight, catering, airport)
- **Aviation**: Air transport + in-kind services to produce air transport services (manufacturing of airplanes and traffic control systems)

Systemization of Air Transport:

- Functional specification: Civil/Military
- Transport Object: Passenger/Freight/Post
- Commercial: Public/not public
- Non-commercial (not-public): Factory flights, company (internal), private, state
- Length of leg: Short (2000km), Mid (5000km), Long
- Legal: Inland(domestic), Cross-border (international)
- Aircraft Type (Engine): Turbo-prop, Jet, Piston engine
- Regularity: Regular (scheduled), On demand (chartered)
- Business model: Network / charter / low cost / business jet

Specialities reg. Supply and Demand In contrast to other modes of transport, air transport has additional, special characteristics:

- Governmental framework conditions (regulations, state carriers, cabotage ban (no provision of transport services within a country by a foreign transport company))
- Special Infrastructure/State Controlled (Airports, air traffic control, SLOT)
- Intermodal Transport (dependency, limited ability to network)
- High fixed costs / perishable inventory (up to 80% fixed costs, production and use of services are combined, external production factor)
- Derived demand by GDP, and income as driver for demand
- Deregulation has increased supply (LCC)

Performance Metrics for Air Transport

- $PKM = PAX \cdot KM$ (passenger km = pax times km)
- $TKM = Tonne \cdot KM$ (transport/tonne km)
- Supply: $ASK = Available\ Seats \cdot KM$ (available seat km)
- Demand: $RPK = Seats\ sold\ (passengers) \cdot KM$ (revenue passenger km)
- $PKM = 1.852 \cdot PM$ (Miles - KM)
- $SLF = RPK/ASK$ (seat load factor in percentage), analogous for CLF (cargo load factor)

Air transport data - Global (IATA) 2017 - see slide 15

Air transport and COVID

- Demand shocks normally do not have long-lasting impacts (previously shocks of RPK minus 5-20%, but recovery after 6-18 months)
- RPK is depending on regions (high RPK in Asia Pacific, Europe, lower in Africa)
- Different markets recover at different paces (depending on vaccine availability, large markets, GDP and leisure markets)
- High uncertainty for prediction: 2036-2037 - uncertainties include: COVID development, Business travels, Global economy, Global security, Climate attitude

Air transport in Europe

- Overall increase in SLF, PKM
- Seasonality: Summer season 50% more flights
- EU traffic mainly stays in EU
- Largest traffic is LDN Heathrow (77m / year) in terms of PAX, Paris in terms of post/freight
- Most of non-EU traffic goes to non-EU Europe (36.4%), North America (19.8%) or Near East (13.3%)
- Strongest Airport pairs: Paris-Tolouse, Madrid-Barcelona, largest growth: Palma de Mallorca
- Nearly all domestic flights, as carriers work in a hub model
- PKM modal split within Europe: Air has 9-10% share, passenger cars 70%, Buses and Coaches 8%, Railways 7%.
- Share of business model within Air transport: 50% traditional scheduled, 32% LCC, 7 % business aviation, 3% Charter (diminishing due to LCC)

Air transport in Switzerland

- Traffic volume in comparison to GDP: Even though share of modes is low, air transport is 17x of Swiss GDP
- Lines and charters: stable at 450'000 movements (starts and landings) per year
- Increase of PAX by 5% over time due to high SLF and larger aircrafts
- Freight and post stable
- 34% of movements in CH are transfers (percentage of ingoing=outgoing transfer)
- Nr of Aircrafts were stable over the years (commercial), private however decreasing (80% of aircrafts in CH for sports purposes)
- In CH: 5.6% of GDP, 33.5 bn CHF value and 190'000 employees

Emissions

- Number of flights probably grow by 42% from 2017 until 2040
- Aviation around 3.6% of EU28 greenhouse emmissions, 13.4% of transport

- Environmental Efficiancy will increase, average fuel burn per passenger by then expected to be -12% and noise reduction by -24%
- CO2 Reduction by 21% and NOX by 16%
- How are these addressed: Technology and Design, Biofuels and Synthetic Fuels, Air Traffic Management, Market based measures

Conversions

- Nautical Mile: 1 NM = 1.852 KM
- Statute Mile: 1 SM = 1.602 km
- Feet: M x 3.281 = FT
- Knot: 1 KT = 1 NM/H = 1.852 KM/H

2 Aircraft Operations

3 Aircraft Aerodynamics

- Lift: Aerodyn. Force perpendicular to the flight vector
- Drag: Aeordyn. Force in opposite direction to flight vector
- Standard condition: $H = 2000m$ and $\rho = 1\ kg/m^3$

Fuel consumption

$$Fuel\ burn\ per\ distance \approx \frac{SFC}{M_\infty}\frac{Weight}{Lift/Drag}$$

M_∞ affected by aerodynamics and Engine, Lift and Drag by Aerodynamics, SFC by engine

Equilibrum of forces: Drag=Thrust (minimse thrust), Lift = Weight (mandatory). Design goal Lift $\gg$ Drag

Flight Performance: How far: c_L/c_D, How long: c_L^3/c_D^2

Forces

$$F_D = c_D\frac{1}{2}\rho_\infty V_\infty^2 A \ \ / \ \ F_L = c_L\frac{1}{2}\rho_\infty V_\infty^2 A = mg = L$$

The fuel consumption depends on the drag "Area": $c_D A$

Eq. of motion

$$Tcos\alpha - D - mgsin\varphi = 0$$
$$L + Tsin\alpha - mgcos\varphi = 0$$
$$\Theta = Attitude = \alpha + \varphi = AoA + flight/climb\ angle$$

Why does a wing generate lift: The wing diverts a mass of air downwards. For this the wing acts with a force to the fluid. In return the air generates a force of the same magnitude to the wing (actio = reactio).

Induced Drag (Drag due to Lift)

$$D_i = \frac{2}{\rho V^2 \pi}\left(\frac{L}{b}\right)^2 \quad , \quad F^* = \pi/4b^2(Prandtl)$$
$$c_{D_i} = \frac{1}{\pi}c_L^2\frac{F}{b^2} = \frac{c_L^2}{\pi\Lambda}$$
$$b = Wing\ Span, F = Wing\ Area, \Lambda = Aspect\ Ratio$$

- Induced drag (D_i) depends on ratio of lift and wing span
- The coefficent of induced drag (c_{D_i}) depends on the aspect ratio
- A slim wing with high aspect ratio produces less induced drag than a compact wing with small aspect ratio
- Induced Drag stems from the principle of linear momentum. No friction is included. The induced drag is an additional contribution to total drag
- In general however, for non elliptical lift distribution, an Oswald-Factor e must be considered $c_{D_{i,true}} = c_{D_i}/e$

Tip Vortices

- Consider Oswald factor e
- Heavy Aircraft $\rightarrow$ Strong tip vortex $\rightarrow$ High Separation Distance / Time

Drag Total Drag = Induced Drag + Parasite Drag

- Parasite Drag is depending on the Reynolds, Mach number and some velocity regimes
- Influence of Reynolds number: Laminar, turbulent flow and separation. Separation mainly due to pressure drag, turbulent and laminar flow due to friction drag (small contribution)
- Target of small drag: No separation, turbulent downstream and large range laminar flow
- Incluence of Mach Number: At airspeed M $\geq$ 0.7, the flow is no longer incompressible. Additional drag occurs
- Lift and drag depend on the angle of attack. The polar diagram describes the dependence of the lift and drag coefficients on the angle of attack α
- Following components can lead to drag: skin friction drag, induced drag, profile drag, form drag, compressibility drag, interference drag, base drag, trim drag

Flight Performance and characteristics

- Atmosphere: Aerodynamic Forces depend on the air density. The engine power (thrust) depends on the ambient pressure and temperature
- Steady thrust: $tan\varphi = \frac{Tcos\alpha - D}{Tsin\alpha + L}$
- Without thrust: $tan\varphi = \frac{-D}{L} = \frac{-c_D}{c_L} = \frac{height}{distance}$ flight path angle points downwards
- φ is a measure for the aerodynamic quality of an airplane (how far it can travel from a given altitude)

Drag at steady horizontal flight

$$L = mg = c_L\frac{\rho}{2}V^2F$$
$$V = \sqrt{\frac{2mg}{\rho F c_L}}$$
$$c_L = \frac{2mg}{\rho V^2 F}$$
$$D = D_{parasite} + D_{ind} = c_{D,para}\cdot\frac{\rho}{2}V^2F + \frac{\rho}{2}V^2F\frac{c_L^2}{\pi\Lambda e}$$
$$= \frac{\rho}{2}V^2F(c_{D,para} + c_{D,ind}) = K_1V^2 + K_2\frac{1}{V^2}$$

The function $D(V)$ intersects with the function of Thrust $T(V)$ twice due to its shape. There are two optimal points with velocities V_1 and V_2, where there is no excess thrust or drag ($T = D$). However the stall speed is determined as follows with the maximal Lift coefficient from the polar diagram:

$$V_{stall} = \sqrt{\frac{2mg}{\rho F c_{L,max}}} \quad (c_{L,max} = c_{a,max}\ from\ diagram)$$

- The maximum speed (ideally V_2 is determined from the maximum Thrust ($V_max, horiz$))
- The minimum speed is the stall speed $V_{stall} > V_1$
- The speed range is between minimum and maximum speed

Stability control

- Steady flight condition $\rightarrow$ Disturbance $\rightarrow$ Answer of airplane $\rightarrow$ Flight path
- Example: Horizontal flight, then Pilot command: elevator deflection or gust comes, then pitching moment, then determine if stable/unstable/indifferent
- $alpha$, $\Delta\alpha > 0$, $-\Delta c_m$, $\frac{dc_M}{d\alpha} > 0$ (positive criterion)

- Lilienthal: Positive long. stability, Wright: Negative long. stability
- Dassault Falcon: stable, Neuron (delta wing): instable, Raffale: indifferent/neutral

Development trends

Good airplane

- High lift to drag ratio (low drag)
- High ratio of payload to weight (low empty weight)
- High engine efficiency (high ratio of engine diameter to shaft power for propeller) + high compressor, combustor and turbine efficiency

Highest efficiency drivers

- Engine: -15% (high combustion efficiency, geared fan)
- Energy: -5 % (no bleed air, more electric aircraft)
- Aerodynamics: -10 % (Wing tip, engine integration, empennage config, Detail improvement)
- Structure: -5% (Detail improvment, composites, new alloys, new joining technologies)
- Air traffic management
- New configurations revolutions vs. tube-wing evolution (curent)
- Electric/hybrid aircraft - new design freedom

4 Manufacturing and Maintenance

Abbreviations:

- A/C: Aircraft
- AMP: Aircraft Maintenance Program
- CAMO: Continuing Airworthiness Management Organisation
- CRS: Certificate of Release to Service
- DOA: Design Organisation Approval
- EASA: European Aviation Safety Agency
- ETOPS: Extended Range Twin Operations
- FAA: Federal Aviation Agency
- FC: Flight Cycles
- FH: Flight Hours
- IFE: In-flight entertainment
- MEL: Minimum Equipment List
- MOE: Maintenance Organisation Equipment
- MSN: Manufacturer Serial Number
- PFC: Pre Flight Check
- POA: Production Organistion Approval
- STC: Supplemental Type-Certificate
- TC: Type Certificate
- XWB: Extra Wide Body