AE1222 Wing loading thrust loading (I)

Slides comments – updated 3 March 2014

Slide 4 - Note: with "*clean configuration",* it is intended the aircraft configuration with high lifting surfaces and the landing gears (when retractable) in retracted position.

During take off and landing, the high lift devices are extracted (generally not in the same extent: at take off, the high lift devices are generally partially deployed to avoid spoiling the climbing performance of the aircraft) and the landing gears are down. These configurations are **NOT** addressed as "*dirty configurations*"

Slide 5 - The wing loading is defined as the ratio between the gross weight of the aircraft and the area of its lifting surface S.

Since the aircraft changes weight during its mission (mainly because of the amount of fuel used during flight, but also in case of payload release during flight, such as parachutists, bombs and ammunitions, water during firefighting etc..), the wing loading of the aircraft will change too. At the beginning of a flight mission the wing loading is generally higher than at the end of the mission.

N.B. In the wing loading/thrust (power) loading plots that are discussed in the coming slides, the intended wing loading is the one at take off. A more correct notation for the plots would be $(W/S)_{TO}$.

Slide 6 - * See previous lecture on the fuel fraction method

The lower the thrust loading, obviously the smaller the required engine, with obvious consequences on cost, weight and fuel consumption.
A higher wing loading, for a given weight value, implies a smaller wing, which also has consequences on the cost and weight of the whole aircraft.

High wing loading is favourable in terms of cruise speed. Besides, a smaller wing surface (for a given lifting capability) will generate less friction drag.

Furthermore, a higher wing loading allows a better use of the mechanic properties of the airframe materials (materials can be stressed much closer to their allowable loads). On the contrary low structural loads will "under use" the materials properties. Even if thinner structure can be designed, production limitation and other type of load cases prevent to go below certain thickness values.

As it will be discussed in the next aerospace design courses, wings with low wing-loading values are also more sensitive to gusts, which among others, has consequences on the ride comfort.

Slide 8 - The stall speed is the minimum flight speed necessary to balance the aircraft weight in horizontal flight.

CS23.49 Stalling Speed:

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(c) VSO at maximum weight must not exceed 113 km/h (61 knots) for –

(1) Single-engined aeroplanes; and

(2) Twin-engined aeroplanes of 2 722 kg (6 000 lb) or less maximum weight that cannot meet the minimum rate of climb

specified in CS 23.67 (a) (1) with the critical engine inoperative.

The 113 km/h (61 kt) stalling speed applies to the maximum takeoff weight for which the airplane is to be certificated.

The stalling speed should be determined at all weight and c.g. positions defining the corners of the loading envelope to determine the critical condition. The highest stall speed for each weight will be forward c.g. in most cases except for unconventional configurations.

CS 25 certified aircraft do not have any explicit limitations on the maximum stall speed, however too high values can make the aircraft not attractive. In fact a high stall speed implies also a high **approach speed** (which is **1.2 and 1.3 times the stall speed** for civil and military aircraft, respectively), which affects the ability of the pilot to see and react at the obstacle height at landing.

Often the approach speed is explicitly stated as design requirement; other time it is opportune to select it based on previous, similar aircraft. Once the approach speed is known, the stall speed can be derived dividing the approach speed by 1.2 or 1.3.

A high stall speed also implies a high landing speed, with consequences on the the landing loads, the required braking capacity etc.

Also take off is influenced by the stall speed, just because the take off speed is by definition 1.2 times the stall speed. A high take off speed of course has implication on the take off distance (which becomes longer) and/or on the amount of thrust required to accelerate the aircraft on the ground.

Slide 10 - Data source Roskam

The values of C_{LMAX} for take off and landing conditions are based on the use of high lift devices (HDS) systems of different efficiency. The highest values of course corresponds to more sophisticated HLDs, which yield higher maximum lift coefficient at the expenses of higher cost, weight, complexity etc.

Consider that the C_{LMAX} value you assume here, will become a target to be met during the wing design and HLD sizing phase. Therefore, be careful when assuming too optimistic values...

Note that the values of maximum lift coefficient at landing are generally larger than at take off. Infact, apart from extra lift, HLD generate also drag, which is not a problem at landing (it just help slowing the aircraft) but requires extra power at take off to accelerate and climb efficiently.

Typically flaps are fully extended at landing, and partially extended (to reach 80% of maximum lifting capability) at take off.

Slide 11 - * To ensure the aircraft can operate also on airports located at high altitude, in dry and hot environment (e.g. Denver airport), it is opportune to check the maximum allowable wing loading factor for $\rho = 0.974$ kg/m^3 (hot day value at 5000 ft – 1524 m altitude)

**Indeed certification tests demand the stall speed measurements to be taken in power off condition (to avoid not conservative estimations caused by positive contributions of the engine and propeller thrust to the lift)

Slide 12 - The area in red represents the part of the design space where the stall speed requirement is not met. Whatever thrust loading value, the wing loading cannot be higher than the limit value shown in the plot.

Slide 13 - *see comments in slide 8, concerning the maximum stall speed for not CS23 aircraft.

Slide 16 - Note that the take off distance includes both the ground roll distance AND the airborne part from lift off point up to the distance required to clear the obstacle height. The obstacle height is 35ft (10.7 m) for civil aircraft, 50ft (15.24m) for military aircraft.

The lift off speed (that is the ground speed required to get the aircraft airborne) is generally 1.1 times the stall speed of the aircraft.

If the **pilot** rotates (put the aircraft nose up) the aircraft too early, the consequent drag can prevent the aircraft to accelerate and reach lift off speed (or anyhow a much longer ground roll can be required). In this sense the pilot technique can have a large influence on the take off distance.

The effect of **ground friction** is obvious. Grass or tarmac will yield different rolling friction coefficient. Also type, wheels number and tyre pressure of landing gears have an impact on the ground friction coefficient.

Slide 17 - If an engine should fail during the takeoff roll at a critical speed, called the **decision speed V_1**, the pilot is offered the option of two safe courses of action:

1. The pilot may decide to continue the takeoff on the remaining engines, in which case, the takeoff distance is defined as the distance from the point at which the takeoff run is initiated to the point where the aircraft has cleared the obstacle height. Such a distance is usually called **OEI take off distance**
2. The pilot may decide to shut down all engines and apply full braking. In this case the distance from the point at which the take of run started to the point where the aircraft has fully stopped (no thrust reverser are allowed for this calculation) is called **Accelerate-Stop distance.**

Generally the decision speed V_1 is chosen in such a way that the OEI take off distance and the Accelerate-Stop distance are the same. In this case, this distance is called the **Balanced Field Length** (BFL).

CS25.113 defines take-off distance the greater distance between the OEI take off length, the accelerate-stop distance, and **115%** of the take off distance when all the engines are operatives.

Considering the fact that normally the decision speed is selected to have a balance field length, the take off distance is generally the longer between the BFL and 115% of the take off distance with all operating engines. For four-engine aircraft the all engines operating condition times 1.15 is usually critical.

Slide 18 - The TOP_{prop} and TOP_{jet} have different units:

In literature, TOP_{jet} is typically expressed in lb/ft^2

On the other hand, different units have been found in literature for TOP_{prop}. The difference is typically due to the different units used to define the engine power. For example, Raymer defines TOP for propeller aircraft using *brake horse power* [bhp], while Roskam uses *horse power* [hp].

$TOP_{prop} \rightarrow lb^2/ft^2 \cdot hp$ (in Roskam)

$TOP_{prop} \rightarrow lb^2/ft^2 \cdot bhp$ (in Raymer),

Given that bhp=ft·lb/s=550hp, it is possible to transform the TOP value provided by one author to the other as follows:
TOP_{prop} (Roskam) = 550·TOP_{prop} (Raymer)

Slide 20 - Plot source: Raymer (fig 5.4)

The plot above allows the estimation of the required TOP parameter once one of the following take off distances is given as requirement:

- Balance Field Length (only for CS25 aircraft. Indeed CS23 aircraft and single engine aircraft do not require meeting BFL requirements)
- Ground roll length for single jet engine and propeller aircraft
- Take off length at 50 ft obstacle clearance for jet and propeller aircraft

For a military multiengine jet aircraft, the balanced field length to clear the 50ft obstacle can be calculated increasing the BFL over 35ft obstacle by 5%.

For a single jet or propeller CS23 aircraft (as well as for twin propeller engine CS23 aircraft) the take off length over 35ft can be found by multiplying the ground roll length by 1.66 (from statistics)

When the plot above does not offer a direct solution for the type of aircraft at hand, it is advised to derive some new curves based on data from reference aircraft.

Of course the plot can be used also in the other way, i.e. to compute the take off distance of an aircraft once its TOP parameter is known.

Note, how twin jets, for a given TOP value (i.e., for a given value of wing and thrust loading), have a longer Balanced Field Length. That is because, when one engine fails, a larger percentage of the overall installed thrust is lost.

Be careful when using the plot above to compute the TOP of propeller aircraft: the engine power is here expressed in Brake Horse Power (BHP), which is the power of the engine measured at the shaft, hence without accounting for any loss due to propeller efficiency. $P=\eta_p \cdot BHP$. **1 HP =550 ft·lb/s=745.6W**

Slide 21 - **N.B.** the CLmax value in this definition of the TOP for **propeller aircraft** is the **actual lift coefficient of the aircraft at takeoff** and NOT the maximum lift coefficient at take-off that is used for stall calculations. The aircraft takes off at about 1.1. times the stall speed, hence the take-off lift coefficient is smaller and equal to the take-off lifting coefficient used for stall speed calculations, divided by 1.21 (which is 1.1 squared).

For Jet aircraft the maximum lift coefficient in the TOP formula is actually the maximum take-off lift coefficient used for the stall calculations.

Slide 23 - Given a certain high lift devices system, aircraft with higher wing loading (smaller wings) will require higher thrust loading (more powerful engines) to meet the take-off length requirement.

Slide 24 - When also the stall speed requirements are considered, the combination of wing and thrust loading values that is able to meet both requirements **at the same time** is further reduced.

Slide 26 - Similarly to the case of jet engines, high value of wing loading require high power (i.e., low W/P values) to meet the take-off length requirement.

Slide 28 - Roskam provides, still base on statistics some other relationships to relate take off length and TOP for jet and propeller aircraft.

Slide 29 - Note that the large scatter obtained in this case. However a linear regression would have yielded even a worse result the the second order fit shown above.

Slide 30 - *As matter of fact the plots previously shown have been generated using the method above to calculate the TOP curve.

Slide 41 - Difference between minimum and maximum as percentage of the average value for the take-off distance (EUROENAER Eaglet flight tests)

clean configuration	17 %
intermediate flaps	21 %

Slide 42 - Difference between minimum and maximum as percentage of the average value for the landing distance (EUROENAER Eaglet flight tests)

clean configuration	30 %
intermediate flaps	43 %
full flaps	26 %

Slide 44 - For military aircraft the landing field is often defined as for CS23 aircraft. Often only the ground roll is given as requirement

46 - $V_A \geq 1.3\ V_{SLand}$ For passenger aircraft CS23 and CS 25

$V_A \geq 1.2\ V_{SLand}$ For military aircraft

Slide 47 - Speed in m/s

Landing field in m

Slide 48 - Note that f is not derived from the weight fraction method discussed in previous lecture. The f value comes from the take-off/landing weight ratio generally given as top level requirement. In case f is not given as requirement you can find in the table next slides some typical values.

Slide 49 - For propeller aircraft the take-off/landing ratio is generally equal to one.

Slide 51 - CLmax is the maximum lifting coefficient at landing conditions, hence with HL devices fully deflected

Slide 54 - The statistical coefficient accounts also for the fact that the actual landing field length (ground plus air distances) should be increased by 2/3 for security reason.

Slide 59 - The A10 uses the split ailerons as airbrake.

Slide 61 - Although the landing field length stipulated by certification regulations are computed without accounting for the effect of thrust reversers, they are actually used in mostly all kind of aircraft to reduce the actually required landing field and increase safety