TOTAL TAKE OFF WEIGHT ESTIMATION ON NOSE WHEEL LANDING GEAR

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Abstract : ***Landing gear is the undercarriage of an aircraft and is often referred to as such. For aircraft, the landing gear supports the craft when it is not flying, allowing it to take off, land and usually to taxi without damage. Wheels are typically used but skids, skis, floats or a combination of these and other elements can be deployed depending both on the surface and on whether the craft only operates vertically (VTOL) or is able to taxi along the surface. Faster aircraft usually have retractable undercarriage, which folds away during flight to reduce air resistance or drag. For launch vehicles and spacecraft landers, the landing gear is typically designed to support the vehicle only post-flight, and is not used for takeoff or surface movement. There is a need to design landing gear with minimum weight, minimum volume, high performance, improved life and life cycle hence; the purpose the present work is to estimate the total takeoff weight on aircraft Nose wheel landing gear. Many technologies have been developed over the years to meet these challenges. The most critical part in the landing gear is the strut.***

INTRODUCTION The purpose is to introduce a technique to obtain the first estimate of the maximum take-off weight (or all-up weight) for an aircraft before it is designed and built. The word estimation is intentionally selected to indicate the degree of the accuracy and reliability of the output. Hence, the value for the maximum take-off weight is not final and must be revised in the later design phases. The result of this step may have up to about 20% inaccuracies, since it is not based on its own aircraft data. But the calculation relies on the other aircraft data with similar configuration and mission. Thus, we are adopting the past history as the major source of the information for the calculation in this step. At the end of the detail design phase, the take-off weight estimation is repeated by using another more accurate technique. The aircraft design nature in iterative, thus, a new data for the maximum take-off weight requires a new round of calculations and new designs for all aircraft components such as wing, tail and fuselage.

1.Maximum Take-Off Weight Estimation The general technique to estimate the maximum take-off weight is as follows: the aircraft weight is broken into several parts. Some parts are determined based on statistics, but some are calculated from performance equations. Maximum take-off weight is broken into four elements:

1. Payload weight (W_{PL})
2. Crew weight (W_C)
3. Fuel weight (W_f)
4. Empty weight (W_E)

$$W_{TO} = W_{PL} + W_C + W_F + W_E \quad \ldots[1.1]$$

The payload weight and crew weight are almost known and determined from the given data (by customer and standards) and are not depending on the aircraft take-off weight. On the other hand, the empty weight and fuel weight are both functions of the maximum take-off weight. Hence, to simplify the calculation, both fuel weight and empty weight are expressed as fractions of the maximum take-off weight. Hence:

$$\mathrm{W_{TO}} = \mathrm{W_{PL}} + \mathrm{W_C} + \left(\frac{\mathrm{W_F}}{\mathrm{W_{TO}}}\right)\mathrm{W_{TO}} + \left(\frac{\mathrm{W_E}}{\mathrm{W_{TO}}}\right)\mathrm{W_{TO}} \quad \ldots[1.2]$$

Thus:

$$W_{TO} = \frac{W_{PL}+W_C}{1-\left(\frac{Wf}{WTo}\right)-\left(\frac{WE}{WTo}\right)} \quad \ldots[1.3]$$

In order to find WTO, one needs to determine four variables of WPL, WC, Wf/WTo and WE/WTo. The first three parameters, namely payload, crew, and fuel fraction are determined fairly accurately, but the last parameter (i.e. empty weight fraction) is estimated from statistics.

1.1 Payload Weight The payload is the net carrying capacity of an aircraft. An aircraft is originally required and designed to carry the payload or useful load. The payload includes luggage, cargo, passenger, baggage, store, military equipment, and other intended loads. Thus, the name payload has a broad meaning.

In determining the total weight of passengers, it is wise to consider the worst case scenario which is the heaviest possible case. It means that all passengers are considered to be adult and male. Although this is a rare case, but it guarantees the flight safety. In a passenger aircraft, the water and food supply must be carried in long trips. But these are included in the empty weight.

Table 1.1 Standard average passenger weights

No	Passenger	Weight Per Passenger (*lb*)	
		Summer	Winter
1	Average adult	190	195
2	Average adult male	200	205
3	Average adult female	179	184
4	Child weight (2 years to less than 13 years of age)	82	87

The weight of luggage and carry-on bag is another item that must be decided. FAA has some recommendations about the weight of bag and luggage in a passenger aircraft. But due to high rising fuel cost, airlines have regulated the weight themselves. For instance, majority of airlines are currently accepting two bags of 70 lbs for international flight and one bag of 50 lbs in domestic flight.

1.2 Crew Weight Another part of the aircraft weight is the weight of the people who are responsible to conduct the flight operations and serving passengers and payload. A human piloted aircraft needs at least one human to conduct the flight. In case of a large passenger aircraft, more staff (e.g. copilot, flight engineer, navigation pilot) may be needed. Moreover, one or more crew is necessary to serve the passengers. In case of a large cargo aircraft, several officers are needed to locate the loads and secure them in the right place.

FAA has regulated the number of crew for transport aircraft. Based on FAR Part 125, Section 125.269, for airplanes having more than 100 passengers, two flight attendants plus one additional flight attendant for each unit of 50 passengers above 100 passengers are required:

Each certificate holder shall provide at least the following flight attendants on each passenger-carrying airplane used: (1) For airplanes having more than 19 but less than 51 passengers—one flight attendant. (2) For airplanes having more than 50 but less than 101 passengers—two flight attendants. (3) For airplanes having more than 100 passengers—two flight attendants plus one additional flight attendant for each unit (or part of a unit) of 50 passengers above 100 passengers.

Therefore, for instance, a large passenger aircraft is required to have two pilots plus eight flight attendants. The followings regulations are reproduced from FAR Part 119, section 119.3:

Crew--for each crewmember required by the Federal Aviation Regulations-- (A) For male flight crewmembers--180 pounds. (B) For female flight crewmembers--140 pounds. (C) For male flight attendants--180 pounds. (D) For female flight attendants--130 pounds. (E) For flight attendants not identified by gender--140 pounds. The following sentence is also reproduced [1] from FAR Part 125, Section 125.9:

Crew -- 200 pounds for each crewmember

1.3 Fuel Weight Another part of the aircraft maximum take-off weight is the fuel weight. The required amount of the total fuel weight necessary for a complete flight operation depends upon the mission to be followed, the aerodynamic characteristics of the aircraft, and the engine specific fuel consumption. The mission specification is normally given to the designer and must be known. The aircraft aerodynamic model and the specific fuel consumption may be estimated from the aircraft configuration that is designed in the conceptual design phase. Recall from equation 1.3 that we are looking for fuel fraction (W_f/W_{TO}).

The first step to determine the total fuel weight is to define the flight mission segments. Three typical mission profiles are demonstrated in Figure 1.1 for three typical aircraft; i.e., transport, fighter, and reconnaissance. Each flight mission consists of several segments, but usually one of them takes the longest time. The main feature of the flight of a transport aircraft is "cruise" that makes the longest segment of the flight.

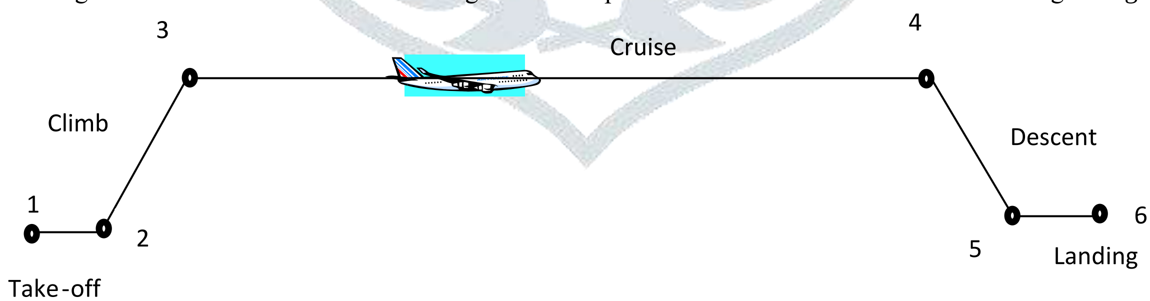

Fig. 1.1 Typical mission profiles for Transport aircraft

For analysis, each mission segment is numbered; with 1 denote the beginning of take-off and 2 is the end of take-off. For example, in the case of a regular flight of a transport aircraft, segments could be numbered as follows: 1. taxi/take-off, 2. climb, 3. cruise, 4. descent, 5. landing. In a similar fashion, the aircraft weight at each phase of the flight mission can be numbered. Hence, W_1 is the aircraft weight at the beginning of take-off (i.e. maximum take-off weight). W_2 is the aircraft weight at the end of take-off which is the beginning of climb phase. W_3 is the aircraft weight at the end of climb phase which is the beginning of cruising phase. W_4 is the aircraft weight at the end of cruising phase which is the beginning of descending phase. W_5 is the aircraft weight at the end of descending phase which is the beginning of landing phase.

Finally, W_6 is the aircraft weight at the end of landing phase. Thus, for any mission segment "*i*", the mission segment weight fraction is expressed as (W_{i+1}/W_i). If these weight fraction can be estimated for all of the segments, they can be multiplied together to find the ratio of the aircraft weight at the end of flight operation, divided by the initial weight; i.e. maximum take-off weight. This ratio would then be employed to determine the total fuel fraction.

$W_{TO} - W_{Land} = W_f$ …[1.4]

Thus, in a regular flight mission, the ratio between the aircraft weight at the end of flight to the aircraft weight at the beginning of flight is:

$\frac{W_{Landing}}{W_{TO}} = \frac{W_{TO}-W_F}{W_{TO}}$ ….[1.5]

Therefore, for the case of a mission with 5 segments as shown in figure 1.2-1, the fuel weight fraction is obtained as follows:

$\frac{W_F}{W_{TO}} = 1 - \frac{W_6}{W_1}$ …[1.6]

Where $\frac{W_6}{W_1}$ can be written as:

$\frac{W_6}{W_1} = \frac{W_2}{W_1} \times \frac{W_3}{W_2} \times \frac{W_4}{W_3} \times \frac{W_5}{W_4} \times \frac{W_6}{W_5}$ …[1.7]

For other flight missions, the reader is required to identify the segments and to build a similar numbering system to derive a similar equation. For the sake of flight safety, it is recommended to carry a reserve fuel in case that the intended airport is closed, so the aircraft has to land on another nearby airport. FAA regulation requires the transport aircraft to carry 20% more fuel than needed or a flight of 45 minutes to observe the airworthiness standards. The extra fuel required for safety purposes is almost 5 percent of aircraft total weight, so it is applied as follows:

$\frac{W_F}{W_{TO}} = 1.05\left(1 - \frac{W_6}{W_1}\right)$ …[1.8]

Therefore, in order to find the fuel weight fraction, one must first determine these weight fractions for all of the mission segments. There are primarily six flight segments as take-off, climb, cruise, loiter, descent, and landing. These flight phases or segments can be divided into two groups:

Table 1.2 Typical average segment weight fractions

No	Mission segment	W_{i+1} / W_i
1	Taxi and take-off	0.98
2	Climb	0.97
3	Descent	0.99
4	Approach and landing	0.997

For an aircraft with the jet engine (i.e. turbojet and turbofan), the optimum range equation with the specified speed of V(L/D)max is:

$R_{Max} = \frac{0.866 V_{Rmax}}{C}\left(\frac{L}{D}\right)\ln\left(\frac{W_i}{W_{i+1}}\right) = \frac{0.866 V_{Rmax}}{C}\left(\frac{L}{D}\right)\ln\frac{W_4}{W_3}$ …[1.9]

$\frac{W_4}{W_3} = e^{\frac{-R.C}{0.866/\left(\frac{L}{D}\right)}}$ …[1.10]

1.4 Empty Weight The last term in determining maximum take-off weight in equation 1.3 is the Empty Weight fraction $\left(\frac{W_E}{W_{TO}}\right)$ at this moment (preliminary design phase), the aircraft has been design only conceptually, hence, there is no geometry or sizing. Therefore, the empty weight fraction cannot be calculated analytically. The only way is to past history and statistics. Table 1.3 shows the empty weight fraction for several aircraft. The only known information about the aircraft is the configuration and aircraft type based on the mission.

Table 1.3 Empty weight fraction for several aircraft

No	Aircraft	Type	Engine	S (m^1)	m_{TO} (kg)	m_E (kg)	$\frac{WE}{W_{TO}}$
1	Voyager	Circumnavigation	piston	30.1	4398	1020	0.23
2	Questair Spirit	Sport homebuilt	Piston	6.74	771	465	0.6
3	Skystar Kitfox V	Kit-built	Piston	12.16	544	216	0.397
4	Beech Bonanza A36	Utility	Piston	16.8	1,655	1,047	0.63
5	Air & Space 20A	Autogyro	Piston	11.33[2]	907	615	0.68
6	Stemme S10	Motor glider	Piston	18.7	850	640	0.75
7	BN2B Islander	Multirole transport	Turboprop	30.19	2,993	1866	0.62
8	C-130H Hercules	Tactical transport	Turboprop	162.12	70,305	34,686	0.493
9	Saab 2000	Regional transport	Turboprop	55.74	22,800	13,800	0.605
10	ATR 42	Regional transport	Turboprop	54.5	16,700	10,285	0.616
11	Air Tractor AT-602	Agricultural	Turboprop	31.22	5,443	2,471	0.454
12	Cessna 750	Business jet	Turbofan	48.96	16,011	8,341	0.52
13	Gulfstream V	Business jet	Turbofan	105.63	40,370	21,228	0.523

$$\frac{W_E}{W_{TO}} = aW_{TO} + b \quad \ldots[3.11]$$

where a and b are found in Table 1.4. Note that the equation 1.10 is curve fitted in British units system. Table 1.4 illustrates statistical curve-fit values for the trends demonstrated in aircraft data, the assumption is that the either the entire aircraft structure or majority of aircraft components are made up of aluminium. The preceding take-off weight calculations have thus implicitly assumed that the new aircraft would also be constructed of aluminium. In case that the the aircraft is expected to be made up of composite material, the value of $\frac{W_E}{W_{TO}}$ must be multiplied by 0.9. The values for GA aircraft in Table 3.8 are for Normal aircraft. If a GA aircraft is of utility type, the value of $\frac{W_E}{W_{TO}}$ must be multiplied by 1.03. If a GA aircraft is of acrobatic type, the value of $\frac{W_E}{W_{TO}}$ must be multiplied by 1.06

Practical Steps of the Technique

The technique to determine the aircraft maximum take-off weight has eleven steps as follows: **Statement :-** To design a conventional civil transport aircraft that can carry 120 passengers plus their luggage. The aircraft must be able to fly with a cruise speed of Mach number 0.8, and have a range of 6500 km. The aircraft is equipped with two high bypass ratio turbofan engines and is cruising at 35,000 ft altitude.

Step 1: Establish the flight mission profile and identify the mission segments

The aircraft is stated to be civil transport and to carry 172 passengers. Hence, the aircraft must follow FAR Part 25. Therefore, all selections must be based on Federal Aviation Regulations. The regular mission profile for this aircraft consists of taxi and take-off, climb, cruise, descent, and landing.

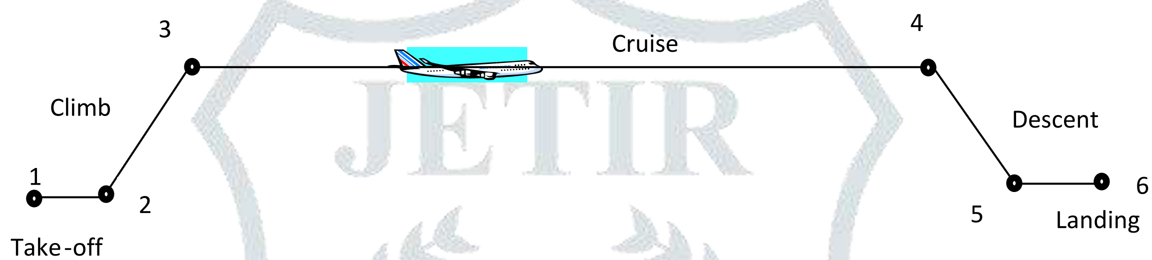

Fig. 3.1 Mission profile for the transport aircraft

Step 2: Weight of flight crew and attendants

The number of flight attendants is regulated by FAR Part 125, Section 125.269: For airplanes having more than 100 passengers, two flight attendants plus one additional flight attendant for each unit of 50 passengers above 100 passengers.

Since there are 172 passengers, number of flight attendants must be 4 and 2 pilots . Flight crew members are assumed to have a weight of 200 lbs. Therefore total weight of the flight crew is :

$W_C = \text{No. of Flight crew} \times \text{weight of one crew member} = 6 \times 200 = 1200$ lbs

Step 3: The weight of payloads

The payload for a passenger aircraft primarily includes passengers and their luggage and baggage. Passengers could be a combination of adult males, adult females, children, and infants. Table 3.1 shows the nominal weight for each category. To observe the reality and to be on the safe side, an average weight of 200lb is selected. On the other hand, 70 lbs of luggage is considered for each passenger. So the total payload would be:

$W_{PL} = (\text{Avg. weight of a person} + \text{weight of luggage}) \times \text{No. of passengers}$ = (200+70) × 172) = **46440 lbs**

Stage 4: Fuel weight ratios for the segments of taxi, take-off, climb, descent, approach and landing

From Table 1.2 we have,

Taxi, take-off: $\frac{W_2}{W_1}$ = **0.98**, Climb: $\frac{W_3}{W_2}$ = **0.97**, Descent: $\frac{W_5}{W_4}$ = **0.99**, Approach and landing: $\frac{W_6}{W_5}$ = **0.997**

Step 5: Fuel weight ratio for the segment of range

In this flight mission, cruise is the third phase of flight which is $\frac{W_4}{W_3}$ and the type of engine is Turbofan engine. From eqn. 3.10

$$\frac{W_4}{W_3} = e^{\frac{-R.C}{0.866\, V/\left(\frac{L}{D}\right)}} \quad = e^{\frac{-3860000\times3.28\times\frac{0.4}{3600}}{0866\times586.61\times13}} \quad = e^{-0.21} \quad = \mathbf{0.810}$$

Where, R = 3860000, C = 0.7 (From reference data), $\frac{L}{D} = 13$ (From reference data), V = M × a = 0.6× 298 = 178.8 m/s = **586.61 ft/s**

Step 6: Overall fuel weight ratio

By using equation,

$\frac{W_6}{W_1} = \frac{W_2}{W_1} \times \frac{W_3}{W_2} \times \frac{W_4}{W_3} \times \frac{W_5}{W_4} \times \frac{W_6}{W_5}$ = 0.98× 0.97 × 0.81 × 0.99 × 0.997 = 0.7599

Substituting the value in eqn. 1.8

$\frac{W_F}{W_{TO}} = 1.05\left(1 - \frac{W_6}{W_1}\right) = 1.05\times(1 - 0.7599)$ = **0.25210**

Step 7: Substitution

Substituting the values in eq. 1.3, $W_{TO} = \frac{W_{PL}+W_C}{1-\left(\frac{Wf}{WTo}\right)-\left(\frac{WE}{WTo}\right)} = \frac{46440+1200}{1-0.25210-\frac{W_E}{W_{TO}}}$

Step 8: Empty Weight

From eqn. 1.11 and table 1.4,

a = -7.754×10^{-8} and b = 0.576, $\frac{W_E}{W_{TO}} = aW_{TO} + b = 7.754 \times 10^{-8}\, W_{TO} + 0.576$

Step 9: Solve the equation analytically

Use Trial & Error method to determine the max. Take off weight of an aircraft.

Step 1: $\mathbf{W_{TO} = 100000}$ **lbs** = **265108.51 lbs**

Step 2: w_{TO} = **122027.5 lbs = 247536.44 lbs**

Step 3: w_{TO} =**247536.44 lbs** = **249301.42 lbs**

Step 4: $\mathbf{w_{TO} = 249301.42}$ **lbs = 249123.0074 lbs**

Step 5: $\mathbf{w_{TO}}$ **= 249123.0074 lbs = 249163.17 lbs**

Thus, the total take-0ff weight of an aircraft is **249163.17 lbs** i.e. **113018.513 kg.**

RESULTS & CONCLUSION

The total takeoff weight of an aircraft MD-90 having passenger capacity of 172 persons and 4 flight attendants plus 2 pilots is **249163.17 lbs** i.e. **113018.513 kg.** We considered a nose wheel landing gear of an aircraft and 15% of total takeoff weight is shared by it. Hence,=113018.513 × 0.15= 16,952.77 kg

Which means the load shared by the Nose Wheel landing gear is 16,952.77 kg and it has a range of 3867 km and specific fuel consumption of 6172.94 lb/hr i.e 2800 kg/hr. In this work the preliminary design of a 172-seater passenger aircraft. These calculations are based on preliminary design of aircraft and they need to be iterated again and again as the data of the aircraft gets frozen.

When shocks occur caused by hard landings and by taxiing over rough surfaces they are absorbed efficiently by oleo-pneumatic shock absorbers and tyres. Thus, the most effective type of shock absorber system is oleo-pneumatic shock strut.

The future holds many new developments in landing gear shock absorbers, as we strive towards an endless pursuit of performance. There are many innovative energy absorption principles capable of shock absorption in aircraft landing gear.

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