International Standard ISO 7717

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Aircraft — Four-wheel-drive tow tractors — Performance requirements factors for design

Aéronefs — Tracteurs d'aéronefs à quatre roues motrices — Paramètres de conception

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Foreword

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Aircraft — Four-wheel-drive tow tractors — Performance requirements factors for design

1 Scope and field of application

This International Standard identifies and summarizes the various factors that shall be considered and evaluated by the design or specifying engineer in establishing performance requirements for four-wheel-drive aircraft tow tractors.

The International Standard provides a summary of design factors that shall be considered in establishing performance requirements, as well as various tabulated design data and explanatory examples.

It is not within the scope of this International Standard to specify a comprehensive set of design criteria for aircraft tractors, but only those relating to performance requirements.

2 Design factors

The following design factors shall be considered and evaluated in establishing aircraft tow tractor performance requirements.

2.1 Aircraft characteristics

The parameters to be taken into account are the following:

a) dimensions;

b) number of landing gear and wheels;

c) attach point for towing;

d) gross weight, empty weight, and weight distribution on the wheels;

e) breakaway resistance of the aircraft as a percentage of aircraft weight for initial motion directed

1) straight ahead,

2) in a turn;

f) rolling resistance of the aircraft as a percentage of aircraft weight for constant motion on various surfaces on

1) a horizontal plane,

2) a grade;

g) turn radius of the aircraft;

h) angularity limitation of the aircraft tow fitting;

j) strength of the aircraft tow fitting when loads are applied

1) directly fore and aft,

2) in the direction of minimum strength;

k) amount of thrust of engines at idle.

2.2 Airport environment

The parameters to be taken into account are the following:

a) maximum grades to be negotiated;

b) minimum speeds required for crossing active taxiways and runways;

c) parking requirements:

1) parallel or nose-in at gates,

2) spacing from other aircraft,

3) proximity to other fixed physical features,

4) need for remote parking;

d) paving strength and surfacing of ramps, taxiways, runways and access roads;

e) road clearance and bridge and overpass limitations;

f) anticipated towing distances and routes between aircraft maintenance/storage areas and cargo/passenger terminals;

g) maximum approach and breakover angles to be negotiated on ramps, taxiways, runways and access roads;

h) other towing equipment limitations, physical or regulatory, unique to the local situation.

2.3 Tow vehicle — General characteristics

The parameters to be taken into account are the following:

a) dimensional limitations;

b) visibility requirements;

c) operator's location(s);

d) steering characteristics to accommodate the requirements identified in 2.1 and 2.2 for the possible configuration of

1) single axle,

2) multiple axle,

— co-ordinated steering,

— crab steering;

e) braking capability;

f) wheels and tyres to accommodate the requirements identified in 2.2 and 2.5;

g) vehicle power and power train;

h) maintenance requirements and service accessibility;

j) requirements for integral electrical power equipment to support the aircraft systems during towing and standby operations;

k) method of attachment to the aircraft (e.g. type and location of the tow hitch);

m) requirements for ground control communications;

n) operational lighting and service compartment lighting;

p) environmental protection for operator's location;

q) special requirements imposed by aircraft manufacturers and/or regulatory bodies;

r) special requirements imposed by the tractor owner.

2.4 Tow vehicle — Power train requirements

The parameters to be taken into account are given in 2.4.1 to 2.4.3.

2.4.1 Engine power

The tow vehicle shall be capable of developing enough power to move both the tow vehicle and the aircraft under the design considerations of weight, direction, speed, surface conditions and resistance to motion.

2.4.2 Rim pull

It is necessary to consider the engine power and torque, the nature of the drive, which may be a torque converter and transmission, a generator and electric motor, or other type, plus the axle and wheel characteristics, to ensure that adequate torque is developed and transmitted as available rim pull to move the towing and towed vehicles. Note that "rim pull" is the effort available at the ground due to the tractor driving mechanism. For the tractor to move itself, its resistance to motion shall be subtracted from "rim pull". This is the towing capability usually referred to as "drawbar pull".

2.4.3 Applied force limits

Consideration shall be given to a means of limiting the forces applied to the aircraft tow fittings to prevent damage to them. This may be accomplished through the use of shear devices in the aircraft towbar or through a means of limiting the drawbar pull of the tow vehicle (i.e. imposing a torque limit on the available rim pull or removing ballast from the tractor).

2.5 Tow vehicle — Weight and traction

2.5.1 Weight

The ability of a tow vehicle with sufficient power to start a given load without slipping its wheels is dependent upon its weight. When the resistance to motion has been defined for the specific design situation, the weight required to allow the tow vehicle to develop the drawbar pull necessary to accomplish the desired motion on a surface with a given coefficient of friction can be determined.

For this purpose, the weight of the tow vehicle is considered as being equally distributed on the four wheels. The effect of load transfer due to the drawbar height, and to acceleration or deceleration is not considered, since it is usually of minor effect.

2.5.2 Traction

Traction needs can be changed to match changing friction coefficients by specifying the capability to ballast the tow vehicle to higher weights. However, the transmitted engine power shall be suitable to use the extra ballast weight. Single and multiple wheel slippage may also be alleviated by specifying the use of such items as "limited slip" differentials that transmit the available torque to the wheel(s) that are not slipping.

3 Design data, explanations and examples

3.1 General

The following items, although correct at this time, should only be considered as general guidance. It is highly recommended that the design or specifying engineer re-verify any data that he uses for a specific situation. The multiple and interrelated factors affecting the towing forces make it impossible to devise formulae that account for all variables.

3.2 Acceleration resistance (AR)

This is the inertial resistance to a change in velocity that shall be overcome to cause an aircraft on a level surface to move from standstill to some constant speed, or from one constant speed to another constant speed.

The factor normally used to calculate aircraft AR is 0,5 % of the aircraft weight for each 0,05 m/s^2 of acceleration. Thus, if the desired acceleration is 0,15 m/s^2 to minimize impact loading, then

$$\text{AR} = 0{,}5\ \% \times \frac{0{,}15\ \text{m/s}^2}{0{,}05\ \text{m/s}^2} \times \text{aircraft weight}$$

$$= 1{,}5\ \% \times \text{aircraft weight}$$

3.3 Rolling resistance (RR)

This is a dynamic resistance which is composed of the friction between the tyres and the surface on which they move, the friction of the wheel bearings and the adhesion between the tyres and the surface on which they move.

The force required to overcome this resistance can be expressed as a percentage of the weight of the aircraft to be moved. It is the force, in kilonewtons, needed to keep the aircraft rolling at a constant speed over a level surface. Based on empirical tests, various factors of rolling resistance have been developed and are tabulated as follows:

Surface type	RR (% of aircraft weight)	
	Dry surface	Wet surface
Hard asphalt	1,4	1,8
Concrete road	1,8	2,2
Snow and ice	2,0	2,5
Snow (hard packed)	2,5	3,1
Snow (soft)	3,3	4,1

Under normal conditions, RR is usually considered to be about 1 to 2 % of aircraft weight in a straight pull and 2 to 4 % in a turning manœuvre. An average rolling resistance of 2 % is considered reasonable and RR = 2 % of aircraft weight.

3.4 Grade resistance (GR)

This is the amount of drawbar pull needed to maintain movement of an aircraft at constant speed on a given grade. GR is considered to be 1 % of aircraft weight for each 1 % of grade. Percent of grade is the number of metres vertical rise for every 100 m in the horizontal.

Generally, for airports, an average grade of 2 % is considered reasonable and the GR = 2 % of aircraft weight.

3.5 Engine thrust (ET)

The thrust produced by idling jet engines is an important consideration in determining tow tractor design criteria. Although the thrust can be positive or negative, depending upon whether the aircraft is being towed forwards or backwards, the primary concern is for the thrust produced during a push out operation. This thrust is additive to the other factors resisting motion of the aircraft and shall be overcome by the tractor. The total force, in kilonewtons, produced by engine thrust will vary depending on the type of engine and the number of engines running. Idle thrust data are available from the engine manufacturer. The number of engines started prior to push out, if any, is a matter of individual airline operating procedure.

3.6 Breakaway resistance (BR)

This is the sum of the inertial and frictional resistances to initial motion offered by the aircraft which shall be overcome to start the aircraft moving. The highest value of static resistance to motion occurs at that point at which motion is impending. Therefore, at the point of impending motion, the combined value of the acceleration and rolling resistances is higher than it is after motion has been initiated. This static breakaway resistance (BR_s) is considered to be 4 % of aircraft weight on a straight pull and nearly 8 % in a turn. Total breakaway resistance (BR_t) is:

$$BR_t = BR_s + GR + ET$$

As soon as the aircraft begins to move, the breakaway requirement falls off and the acceleration and rolling resistances revert to their dynamic values. Average BR_s = 4 % of aircraft weight.

3.7 Rim pull (RP)

This is the total force, in kilonewtons, which is available at the outer radius of the tractor tyres for transmission to the surface on which the tyres rotate:

$$RP = \frac{T \times R \times e \times C}{r}$$

where

T is the gross engine torque, in kilonewton metres;

R is the overall gear reduction of the drive train;

e is the mechanical efficiency of the drive line;

C is the correction factor for engine torque to determine net torque available at the flywheel;

r is the rolling radius of the loaded driving tyres, in metres.

3.8 Tractive effort (TE)

Assuming adequate rim pull is available, TE is the maximum force which can be exerted by the tractor to produce motion without slipping the wheels. It is a function of the tractor weight and the coefficient of traction of the surface:

$$TE = u \times \text{tractor weight}$$

The coefficient of traction (u) is a series of constants for varying road surface conditions. These constants are normally tabulated as follows:

Condition	u
Average	0,45
Glaze ice	0,10
Wet asphalt	0,40
Dry asphalt	0,80
Wet concrete	0,50
Dry concrete	0,80
Hard snow	0,20
Oily concrete	0,40

3.9 Drawbar pull (DBP)

3.9.1 Drawbar pull available (DBP_a)

This is the force, in kilonewtons, which the tractor is capable of producing at its tow hitch. It is the tractive effort minus the force required to move the tractor. Assuming, with the exception of engine thrust (ET), that the same resistances to motion which apply to the aircraft also apply to the tractor:

DBP_a (at breakaway)

$= TE - BR_t$ (of the tractor)

$= (u \times$ tractor weight$) - (4\ \% \times$ tractor weight $+$ GR of the tractor)

DBP_a (after breakaway)

$= TE - (AR + RR + GR)$ of the tractor

3.9.2 Drawback pull required (DBP_r)

This is the force required to move the aircraft, i.e.:

DBP_r (at breakaway) $= BR_t$ (of the aircraft)

DBP_r (to accelerate the aircraft on a slope) $= (AR + RR + GR + ET)$

DBP_r (to maintain the aircraft at a constant speed on a slope) $= (RR + GR + ET)$

To make sure that the tractor is sized for the worst condition, it is assumed that the aircraft is being pushed up the slope with engine thrust working against the tractor.

3.10 Examples

It is desired to specify a tractor to move a 250 000 kg aircraft against 25 kN of engine thrust. Design parameters are established as follows:

a) Coefficient of friction = 0,45 (average) or 0,10 (worst)

b) Maximum surface slope = 2 %

c) Maximum tow speed = 16 km/h

d) Coefficient of static breakaway resistance BR_s = 4 % max.

e) Coefficient of acceleration resistance AR = 1,5 % max.

f) Coefficient of rolling resistance RR = 2 % max.

g) Coefficient of grade resistance GR = 2 % max.

h) Assume that resistance constants for the aircraft also apply to the tractor.

j) Drawbar pull required (DBP_r) for breakaway equals the sum of the aircraft resistances or BR_t:

$DBP_r = BR_t = BR_s + GR + ET$

$DBP_r = 0{,}981\,[(0{,}04 \times 250\,000) + (0{,}02 \times 250\,000)] + 2\,500$

$= 9\,810 + 4\,905 + 2\,500$

$DBP_r = 17\,215$ daN ≈ 172 kN

k) The tractive effort of the tractor at breakaway therefore shall equal the drawbar pull required to move the aircraft (DBP_r) plus the force required to move the tractor, i.e.:

$TE = DBP_r + BR_t$ (of tractor)

$= 172 + (BR_s \times$ tractor weight$) + GR$

$= 172 + (0{,}04 + 0{,}02)$ (tractor weight)

$= 172 + 0{,}06$ (tractor weight)

Also

$TE = u \times$ tractor weight

$= 0{,}45 \times$ tractor weight

$172 + 0{,}06$ (tractor weight) $= 0{,}45$ (tractor weight)

$172 = 0{,}45$ (tractor weight) $- 0{,}06$ (tractor weight)

$172 = 0{,}39$ (tractor weight)

$$\text{Tractor weight} = \frac{172}{0{,}39} \approx 441{,}4 \text{ kN}$$

$$\text{Tractor mass} = \frac{441{,}4}{0{,}009\,81} \approx 45\,000 \text{ kg}$$

$TE = 0{,}45 \times 441{,}4 = 198{,}63$ kN ≈ 200 kN

m) For icy conditions $u = 0{,}10$ and

$$\text{Tractor weight} = \frac{172}{0{,}10 - 0{,}06} = \frac{172}{0{,}04} = 4\,300 \text{ kN}$$

Since it would be impractical to ballast the tractor to get this extra weight, an alternative means shall be found to change the coefficient of traction. Consideration should be given to chains, studded tyres, sanding the road surface, etc.

n) The approximate power, in kilowatts, to overcome breakaway for both tractor and aircraft assuming an increase in speed from 0 up to 1 km/h can be computed as

$$\text{Power} = \frac{\text{Required tractive effort (kN)}}{4}$$

The approximate power, in kilowatts, required at various speeds can be expressed as

$$\text{Power} = \frac{\text{Required tractive effort} \times \text{speed (km/h)}}{4}$$

In the breakaway in k)

$$\text{Power} = \frac{200 \text{ kN}}{4} = 50 \text{ kW}$$

Consider the example of accelerating the 250 000 kg aircraft and 45 000 kg tractor from just above breakaway to a speed of 1 km/h up a 2 % grade with the engines off, i.e.:

Power

$$= \frac{TE \times \text{speed}}{4}$$

$$= \frac{(AR + RR + GR)(295\,000 \times \text{speed})}{4}$$

$$= \frac{(0{,}015 + 0{,}02 + 0{,}02)(295\,000 \times 0{,}009\,81 \times 1)}{4}$$

$= 40$ kW