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AEROSPACE INFORMATION REPORT

AIR 1854

Issued March 1985
Revised

BATTERY POWERED AIRCRAFT TOW/PUSHOUT TRACTORS - FACTORS FOR DESIGN CONSIDERATION

1. PURPOSE: This Aerospace Information Report (AIR) identifies and summarizes the various factors that must be considered and evaluated by the design or specifying engineer in establishing performance requirements for two or four-wheel-drive battery-powered aircraft tow/pushout tractors.

1.1 Reference Documents:

ARP 1247B - General Requirements for Aerospace Powered Mobile Ground Support Equipment, Motorized and Nonmotorized

AIR 1353 - Cushioned Tow Hitches Test

AIR 1363 - Four Wheel Drive Aircraft Tow Tractors - Factors for Design Consideration

AS 1614A - Commercial Aircraft Tow Bar Attach Fitting Interface

ARP 1816 - Charger For Battery Powered Ground Support Equipment

ARP 1817 - Battery Industrial, Lead Acid Type For Use in Electric Powered Ground Support Equipment

ARP 1892 - Electrical Connectors For Use in Battery-Powered Ground Support Equipment

2. SCOPE: The AIR is presented in two parts. The first part is simply a summarization of design factors that must be considered in establishing performance requirements. The second part consists of various tabulated design data and explanatory examples.

3. DESIGN FACTORS: The following design factors must be considered and evaluated in establishing aircraft tow tractor performance requirements:

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3.1 Aircraft Characteristics (for various aircraft of the type/weight to be handled):

a. Dimensions

b. Number of landing gear and wheels

c. Attachment points for towing in both forward and aft directions if applicable

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 (with consideration of multi-truck landing gear)

f. Rolling resistance of the aircraft as a percentage of aircraft weight for constant motion on various surfaces

g. Turning radius of the aircraft

h. Angularity limitation of the aircraft tow fitting

i. Strength of the aircraft tow fitting, landing gear, and/or back up structure when loads are applied:

(1) directly fore and aft

(2) in the direction of minimum strength

j. Amount of thrust of engines at idle

3.2 Airport Environment:

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

3.2 (Continued)

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. Anticipated aircraft daily pushout frequencies and distances by type (weight) of aircraft

h. Maximum approach and breakover angles to be negotiated on ramps, taxiways, runways and access roads

i. Other towing equipment limitations, physical or regulatory, unique to the local situation

j. Availability of facilities/capabilities for battery charging

k. Environmental factors:

(1) temperature

(2) Humidity/moisture

(3) altitude

l. Ramp conditions

(1) condition or material of ramp surface

(2) snow or ice

(3) rain

(4) oil or hydraulic fluid

(5) loose material

m. Place to install chargers

3.3 Tow Vehicle - General Characteristics:

a. Dimensional limitations

If underbelly towing is contemplated, particular attention should be given to any aircraft underbelly protrusions, such as antenna, and the clearance between the nose gear rear towbar attach fitting and the wing mounted engine cowlings.

b. Visibility requirements, including windshield defrosting

c. Operator's location(s)

d. Steering characteristics including lapsed time for stop to stop steering to accommodate the requirements identified in 3.1 and 3.2 for the possible configuration of:

(1) single axle

(2) multiple axle

(a) coordinated steering

(b) crab steering

e. Braking capability

f. Wheels and tires, including adequate clearance for snow chains, to accommodate the requirements identified in 3.2 and 3.6

g. Vehicle power and power train

h. Maintenance requirements and service accessibility

i. Requirements for integral electrical power equipment to support the aircraft systems during towing and standby operations

j. Method of attachment to the aircraft (e.g., type, locations and height of the tow hitch)

k. Requirements for ground control communications

l. Operational lighting and service compartment lighting

m. Environmental protection for operators location

n. Special requirements imposed by aircraft manufacturers and/or regulatory groups

3.3 (Continued)

o. Special requirements imposed by the tractor owner

p. Emergency braking system

q. Tow speed and tow distance requirements

r. Pushout tractor limitations relative to plane size

s. Tractor drive: two wheel or four wheel

3.4 Tow Vehicle - Electrical Characteristics:

a. Battery characteristics: (See battery ARP 1817)

(1) Type - flat plate, tubular plate, lead acid, etc.

(2) Voltage

(3) Capacity

(4) Access for service, watering, changing

(5) Removal/installation provisions

(6) Battery layout (i.e. batteries in series, parallel, or single pack)

(7) Battery weight and weight distribution

b. Type charger and charger controls/characteristics (see charger ARP 1816)

c. Type connectors (see connector ARP 1892)

d. Type vehicle controls

e. Safety devices (re: silicon controlled rectifier control safety devices, seat switches, emergency battery disconnect, driveaway interlock, etc.)

f. Waterproofing requirements

g. Fire control provisions

h. Motor overspeed protection for severe grades

i. Accessory circuitry

(1) Converter

(2) Battery

3.5 Tow Vehicle - Power Train Requirements:

a. Motor Horsepower: The tow vehicle must be capable of developing enough horsepower to move both the tow vehicle and the aircraft under the design considerations of weight, direction, speed, surface conditions and resistance to motion.

b. Tractive Force: It is necessary to consider the motor power and torque, the nature of the drive (which may be a mechanical system, a hydromechanical system, or other type) plus the axle and wheel characteristics, to ensure that adequate torque is developed and transmitted onto the wheels as available tractive force to move both the tow tractor and towed aircraft. Note that "tractive force" is the effort available at the ground due to the tractor driving system.

c. Drawbar Pull: This is the part of the tractive force of the tow tractor available to pull or push the aircraft. It is defined in SAE J872A as "Reserve Tractive Force," and is the towing capability of the vehicle.

d. Applied Force Limits: Consideration must 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., torque-limit the available tractive force through the use of electrical or hydraulic power range selectors).

3.6 Tow Vehicle - Weight and Traction:

a. Weight: The ability of a tow vehicle with sufficient horsepower to start a given load without slipping its wheels is dependent upon its weight, and the weight distribution on each traction drive wheel. 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.

In this discussion, the weight of a four-wheel drive tow vehicle is considered as being equally distributed on the four wheels.

In a two-wheel drive vehicle, the actual weight on the two drive wheels must be used to determine the drawbar pull developed. 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.

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

4. DESIGN DATA, EXPLANATIONS AND EXAMPLES:

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

4.2 Acceleration Resistance (AR): This is the inertial resistance to a change in velocity that must be overcome to cause a tow tractor and an aircraft to move on a level surface from a standstill to a constant speed or from one constant speed to another constant speed.

The acceleration resistance (AR) that an aircraft tow tractor must overcome can be calculated with adequate approximation by the formula:

English Units	Metric or S.I. Units
$AR(LBS.) = \dfrac{a(FT./SEC.^2) \times [WA+WT]\ (LBS.)}{g(32.2)\ FT./SEC.^2)}$	$AR\ (NEWTONS) = a(METER/SEC.^2) \times [WA+WT](KG.)$

One Newton (Systems International Unit of Force) is the force equivalent to a mass of one (1) kilogram subject to an acceleration of 1 m/s^2. 1 Newton = 1 kilogram x 1 m/s^2. (Please note that the acceleration due to gravity does not enter into this metric calculation since WA and WT are already in mass units.)

	English Units	Metric Units or (SI Units)
WA = Aircraft Weight (or mass)	LBS.	Kilograms = LBS/2.205
WT = Tow Tractor Weight (or mass)	LBS.	Kilograms
a = Acceleration (of the aircraft and tractor)		
g = Acceleration due to Gravity	32.2 $Ft/Sec.^2$	9.81 m/s^2
Thus, if the desired acceleration is to minimize impact loading, then:	0.5 $Ft/Sec.^2$	.152 m/s^2
AR =	$\dfrac{0.5\ (WA + WT)}{32.2}$ Lbs.	.152(WA + WT) Newtons
=	0.015 (WA + WT) Lbs.	.152 (WA + WT) Newtons
=	1.5% (WA + WT) Lbs.	.15.2% (WA + WT) Newtons

4.3 Rolling Resistance (RR): This is a dynamic resistance which is composed of the friction between the tires and the surface on which they move, the friction of the wheel bearings and the adhesion between the tires and the surface on which they move. The force required to keep the towed aircraft and the towing tractor rolling at a constant speed over a level surface is equal to the rolling resistance.

The rolling resistance (RR) can be expressed as a percent of the weight of the aircraft and the tow tractor.

English Units	Metric or SI Units
RR(LBS.) = f [WA + WT]	RR(Newtons) = f [WA + WT] (KG) 9.81 m/s^2

f = Coefficient of rolling resistance in %

Based on empirical tests, various coefficients of rolling resistance have been developed. Some of them are tabulated as follows:

SURFACE TYPE (x)	DRY (x)	WET (x)
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

(x) These coefficients of rolling resistance are identical to paragraph 4.3 of SAE-Inc., Aerospace Information Report AIR 1363.

Under normal conditions, the coefficient of rolling resistance is usually considered to be 1% (20#/TON) (or .0981 N/kG) to 2% (40#/TON) (or .196 N/Kg) of aircraft weight in a straight pull/push and 2% to 4% (80#/TON) (or .392 N/Kg) of aircraft weight in a turning maneuver. An average rolling resistance of 2% (40#/TON) (or .196 N/Kg) of the weight is considered reasonable.

4.4 Grade Resistance (GR): This is the component of the vehicle weight acting against the movement of the vehicle when it moves up a grade.

The grade resistance (GR) that the tow tractor must overcome in towing an aircraft up a slope can be approximated by the formula:

English Units

GR = G(WA + WT) where

WA = Aircraft Weight (LBS.)

WT = Tow Tractor Weight (LBS.)

G = Grade in % (Ratio of the vertical rise to the projected horizontal distance in %)

At 1% Grade - Rolling Resistance per ton = 20#/Ton

At 2% Grade - Rolling Resistance per ton = 40#/Ton

Metric or SI Units

$GR(Newtons) = G[WA + WT (Kg)] \times 9.81\ m/s^2$

WA = Aircraft weight or mass -(kilograms)

WT = Tow Tractor weight or mass (kilograms)

At 1% Grade - Rolling Resistance per kilogram = .0981N

At 2% Grade - Rolling Resistance per kilogram = .196N

An average grade of 2% is considered reasonable for most airport applications.

4.5 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 forward or backward, the primary concern is for the thrust produced during a pushout operation. This thrust is additive to the other factors resisting motion of the aircraft and must be overcome by the tractor. The total force produced by the engine thrust will vary with 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 pushout, if any, is a matter of individual airline operating procedure.

4.6 Breakaway Resistance (BR): This is the sum of the inertial and frictional resistances of initial motion that a tow tractor must overcome to start itself and the towed 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.

The breakaway resistance (BR) can be calculated by the formula:

English Units	Metric or SI Units
$BR = f_B(WA + WT)$	$BR(Newtons) = f_B[WA + WT (KG)]\ 9.81\ m/s^2$

Where f_B = Coefficient of breakaway resistance in %

An average value for f_B on a straight pull is 4%

Note: The value for f_B can approach 8% in a turn.

4.7 Total Resistance (TR): This is the sum of all resistance which the tow tractor must overcome in towing an aircraft.

As soon as the aircraft begins to move, the breakaway requirements fall off and the acceleration and rolling friction values revert to their dynamic values. The average BR_S is considered to be 4% (80#/TON) (or .392 N/Kg) on a straight pull and nearly 8% (160#/TON) (or .784 N/Kg) in a turn.

English Units (All in LBS) | Metric - SI - (All in Newtons)

a. At breakaway:

$$TR_B = BR_S + GR + ET$$

$$BR_S = fB_S\ (WA + WT); f_B = .06$$

$$= 0.06\ (WA + WT) + ET$$

b. In acceleration to constant velocity:

$$TR_A = AR + RR + GR + ET$$

c. In motion at constant velocity:

$$TR = RR + GR + ET$$

4.8 Tractive Effort (TE): This 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 on the driven wheels (or vertical force in Newtons) and the coefficient of friction between the tires and the airport surface. The total drive system of the vehicle must be capable of producing this TE at the outer "load" radius of the tractor tire.

English	Metric or SI Units
TE (LBS) = u x WT (LBS)	TE (Newtons) = u x WT(KG) x 9.81 m/s^2

TE = u x WT

Where u = Coefficient of friction (Traction)

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

CONDITION (x)	u (ATA) (x)	u (SAE) (x)
Average	.45	-
Glaze Ice	0.10	-
Wet Asphalt	0.40 - 0.60	0.40
Dry Asphalt	-	0.80
Wet Concrete	-	0.50
Dry Concrete	0.80	0.80
Hard Snow	-	0.20
Oily Concrete	-	0.40

(x) These traction (u) coefficients are identical to paragraph 4.8 of SAE Inc., Aerospace Information Report AIR 1363.

The available tractive effort (TE) must equal the total resistance at breakaway (TR).

$$TE = TRB$$

$$= BR + GR + ET$$

This relation permits the tractor weight (WT) to be determined. This (WT) weight would be the total weight for a four-wheel drive tractor with equal weight distribution. For a two-wheel drive tractor this (WT) weight would be the actual required weight on the two driven wheels. As the tractive effort is the total force which is available at the outer radius of the tractor tires, the tractor drive system has to be able to develop and transmit onto the wheels a total torque (TT) as follows:

English Units	Metric Units
TT(LB-FT) = TE(LB) x r(FT)	TT(Newton-Meter) = TE(Newton) x r(Meter)

$$TT = TE \times r$$

where r = Static Loaded Radius of the tire

If the tow tractor is driven by a mechanical system, then the needed motor torque (MT) is:

$$MT = \frac{TT}{R \times e}$$

where R = Overall reduction ratio of drive train

e = Overall mechanical efficiency of drive train

MT, TT are both expressed in LB-FT or Newton-Meter.

4.9 Drawbar Pull (DBP):

a. Drawbar Pull Required: This is the force required to move the aircraft. It is equal to the total resistance of the aircraft. (This definition omits the T.E. required to move the tractor itself.)

(1) At breakaway (DBP_B):

English Units

DBP_B(LBS) $= TRA_B$ (LBS)
$= BRA + GRA + ET$
$= f_B \times WA + G \times WA + ET$
$= (f_B + G)\ WA + ET$

where TRA_B = Total resistance of the aircraft at breakaway
BRA = Breakaway resistance of the aircraft ($BRA = f_B \times WA$)
GRA = Grade resistance of the aircraft ($GRA = G \times WA$)
ET = Engine Thrust

Metric Units

DBP_B(Newtons) $= TRA_B$ (Newtons)
$= BRA + GRA + ET$ (All in Newtons)
$= f_B + (WA \times g) + (G \times WA \times g) + ET$
$= (f_B + G)\ [WA(\text{Kilograms})]\ (9.81) + ET$

$BRA = f_B \times WA(KG) \times 9.81$
$GRA = G \times WA(KG) \times 9.81$
$g = 9.81\ m/s^2$

(2) During acceleration (DBP_A):

English Units

DBP_A (LBS) = TRA_A (LBS.)
= ARA + RRA + GRA + ET
= ARA + f x WA + G x WA + ET
= (f+G) WA + ARA + ET

Metric Units

DBP_A(Newtons) = TRA_B(Newtons)
= ARA + RRA + GRA + ET (All Newtons)
= ARA + (f x WA x g) + (G x WA x g) + ET
= ARA + (f + G) WA(Kg) 9.81 + ET

(3) During motion at constant velocity (DBP_M)

English Units

DBP_M (LBS.) = TRA_M (LBS.)
= RRA + GRA + ET
= (f x WA) + (G x WA) + ET
= (f+G) WA + ET

TRA_M = Total resistance of aircraft in motion

ARA = Acceleration resistance of the aircraft $\left(ARA = \frac{WA \times a}{g}\right)$

RRA = Rolling resistance of the aircraft (RRA = f x WA)

ET = Engine thrust

g = Acceleration due to gravity 32.2 ft/Sec.^{2}

Metric Units

DBP_M(Newtons) = TRA_M(Newtons)
= RRA + GRA + ET (All in Newtons)
= (f x WA x g) + (G x WA) + ET
= (f + G) [WA (Kilograms)] (9.81) + ET

ARA = WA x a

RRA = f x WA

g = Acceleration due to gravity 9.81 m/s^2

b. Drawbar Pull Available: This is the force which the tractor is capable of producing at its tow hitches. It is the tractive effort minus the total resistance of the tractor itself:

At breakaway:

English Units

DBP(LBS.) = TE(LBS.) + TRT

= TE - (BRT + GRT)

= (u x WT) - (f_B X WT) - (G x WT)

= (u - f_B - G) WT

TRT = Total Resistance of the Tractor

BRT = Breakaway Resistance of the tractor (BRT = fB x WT)

GRT = Grade Resistance of the tractor (GRT = G x WT)

Metric Units

DPB(Newtons) = TE(Newtons) = TRT(Newtons)

= TE- (BRT + GRT)

= (u x WT x g) - (f_B X WT x g) - (G x WT x g)

= (u-f_B-G) x WT (Kilograms) x 9.81

BRT = f_B x WT (Kilograms) x g

GRT = G x WT (Kilograms) x g

g = Acceleration due to gravity = 9.81m/s^2