AEROSPACE INFORMATION REPORT

Society of Automotive Engineers, Inc.
400 COMMONWEALTH DRIVE, WARRENDALE, PA. 15096

AIR 1363

Issued November 1976
Revised

FOUR WHEEL DRIVE AIRCRAFT TOW 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 four-wheel-drive aircraft tow tractors.

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.

3.1 Aircraft Characteristics:

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.

3.1 (Continued)

i. Strength of the aircraft tow fitting 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

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.

3.3 Tow Vehicle - General Characteristics:

a. Dimensional limitations.

b. Visibility requirements.

c. Operator's location(s).

d. Steering characteristics 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 to accommodate the requirements identified in 3.2 and 3.5.

3.3 (Continued)

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 and location 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.

o. Special requirements imposed by the tractor owner.

3.4 Tow Vehicle - Power Train Requirements:

a. Engine 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. 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 insure 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 must be subtracted from "rim pull". This is "Reserve Tractive Force", as defined in SAE J872A, and is the towing capability usually referred to as "Drawbar Pull".

c. 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 rim pull or consider removing ballast from the tractor).

3.5 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. 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 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.

3.5 (Continued).

b. 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 must 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.

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 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 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 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 percent of the aircraft weight for each 10 feet per minute per second of acceleration. Thus, if the desired acceleration is 30 feet per minute per second to minimize impact loading, then:

$$AR = 0.5\% \times \frac{30 \text{ fpmps}}{10 \text{ fpmps}} \times \text{Aircraft Weight}$$

$$= 1.5\% \text{ Aircraft Weight}$$

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 overcome this resistance can be expressed as a percent of the weight of the aircraft to be moved. It is the force in pounds 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:

	RR (% Aircraft Wt.)	
Surface Type	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 percent of aircraft weight in a straight pull and 2 to 4 percent in a turning maneuver. An average rolling resistance of 2 percent is considered reasonable and RR 2 percent of aircraft weight.

4.4 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 percent of the aircraft's weight for each one percent of grade. Percent of grade is the number of feet vertical rise for every 100 feet in the horizontal.

Generally, for airports, an average grade of 2 percent is considered reasonable and the GR = 2 percent of Aircraft Weight.

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 push out operation. This thrust is additive to the other factors resisting motion of the aircraft and must be overcome by the tractor. The total force in pounds produced by engine thrust will vary with the type of engine and the number of engines running. Idle thrust data is available from the engine manufacturer. The number of engines started prior to push out, 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 to initial motion offered by the aircraft which must 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 (BRs) is considered to be 4 percent of aircraft weight on a straight pull and nearly 8 percent in a turn. Total breakaway resistance (BR_t) is:

$$BR_t = BRs + GR + ET$$

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 BRs = 4 percent aircraft weight.

4.7 Rim Pull (RP): This is the total force in pounds which is available at the outer radius of the tractor tires for transmission to the surface on which the tires rotate.

$$RP = \frac{T \times R \times e \times C \times 12}{r}$$

where: T = Gross engine torque in lb.-ft.

C = Correction factor for engine torque to determine net torque available at flywheel.

R = Overall gear reduction of drive train.

e = Mechanical efficiency of drive line.

r = Rolling radius of loaded driving tires (inches)

12 = A constant converting lb.-ft. to lb.-in.

4.8 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 (ATA)	u (SAE)
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

4.9 Drawbar Pull (DBP):

a. Drawbar Pull Available (DBPa): This is the force in pounds 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:

DBPa (at breakaway) = TE - BRt (of the tractor) = (u x tractor weight) - (4% tractor weight + GR)

DBPa (after breakaway) = TE - (AR + RR + GR) of the tractor.

b. Drawbar Pull Required (DBPr): This is the force required to move the aircraft.

DBPr (at breakaway) = BRt (of the aircraft)

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

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

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

4.10 Examples: It is desired to specify a tractor to move a 500,000 pound aircraft against 5,000 pounds of engine thrust. Design parameters are established as follows:

a. Coefficient of Friction = .45 Average - .10 Worst

b. Maximum Surface Slope = 2%

c. Maximum Tow Speed = 10 Miles per Hour

d. Static Breakaway Resistance (BRs) = 4% Maximum

e. Acceleration Resistance AR = 1.5% Maximum

f. Rolling Resistance RR = 2% Maximum

g. Grade Resistance GR = 2% Maximum

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

i. Required drawbar pull (DBPr) for breakaway equals the sum of the aircraft resistances or BRt:

DBPr = BRt = BRs + GR + ET

DBPr = (.04 x 500,000) + (.02 x 500,000) + 5000

= 20,000 + 10,000 + 5000

DBPr = 35,000 pounds

j. The tractive effort of the tractor at breakaway therefore must equal the drawbar pull required to move the aircraft (DBPr) plus the force required to move the tractor.

4.10 (Continued)

$$TE = DBPr + BRt \text{ (of tractor)}$$
$$= 35{,}000 + (BRs \times \text{tractor weight}) + GR$$
$$= 35{,}000 + (.04 + .02)\ (\text{tractor weight})$$
$$= 35{,}000 + .06 \text{ tractor weight}$$

also

$$TE = u \times \text{tractor weight}$$
$$= .45 \times \text{tractor weight}$$

$\therefore$ 35,000 + .06 tractor weight = .45 tractor weight

35,000 = .45 tractor weight − .06 tractor weight

35,000 = .39 tractor weight

$\therefore$ tractor weight $= \frac{35{,}000}{.39} = 89{,}743$ pounds

round to 90,000 pounds

$$TE = .45 \times 90{,}000 = 40{,}500 \text{ pounds.}$$

k. For icy conditions u = .10 and

tractor weight $= \frac{35{,}000}{.10 - .06} = \frac{35{,}000}{.04} = 875{,}000$ pounds

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

l. The approximate horsepower to overcome breakaway for both tractor and aircraft assuming an acceleration from 0 miles per hour up to 1 mile per hour can be computed as:

$$HP = \frac{\text{Required tractive effort}}{375}$$

The approximate horsepower required at various speeds can be expressed as -

$$HP = \frac{\text{Required tractive effort} \times \text{Speed in MPH}}{375}$$

In the example j breakaway HP $= \frac{40{,}500 \text{ lb.}}{375} = 108$ HP

Consider the example of accelerating the 500,000 lb aircraft and 90,000 lb tractor from just above breakaway to a speed of 1 MPH up a 2% grade with the engines off

$$HP = \frac{TE \times \text{Speed}}{375} = \frac{(AR + RR + GR)\ (590{,}000) \times \text{Speed}}{375}$$

$$\frac{(1.5 + 2 + 2)\ (590{,}000) \times 1}{375} = 86.5 \text{ HP}$$

Under the same conditions to accelerate to 5 MPH would require 5 x 86.5 = 432.5 HP.