



AEROSPACE INFORMATION REPORT

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Superseding AIR1854A

Battery Powered Aircraft Tow Tractors - Factors for Design Consideration

RATIONALE

AIR1854A has been reviewed. Small editorial changes have been made and coefficient of breakaway resistance introduced for TLTV. Added references to AHM907. Added reference to nose landing gear limits as specified by airframe manufacturers in their TLTV assessment criteria. Added connectors IP grade and charger communication protocol.

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1. SCOPE

This SAE Aerospace Information Report (AIR) identifies and summarizes the various factors that must be considered and evaluated by the design or specifying engineer in establishing the specifications and design characteristics of battery-powered aircraft tow tractors.

This AIR is presented in two parts. The first part is simply a summarization of design factors that must be considered in establishing vehicle specifications and design characteristics. The second part refers particularly to the performance characteristics of an aircraft tow tractor. Some definitions, formulas, data, and an example are provided mainly for assisting the specifying engineers of potential buyers and users of aircraft tow tractors in the evaluation and comparison of their requirements with the performance capabilities of the various tow tractors offered by the tow tractor manufacturers. Although the design engineers could also use the formulas and data in their calculations of the performance specifications of aircraft tow tractors, this AIR is not intended to provide the methods and all data necessary for detailed calculations and design of a battery-powered aircraft tow tractor.

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

- ARP1816 Charger for Battery Powered Ground Support Equipment
- ARP1817 Battery Industrial, Lead-Acid Type, for Use in Electric Powered Ground Support Equipment
- ARP1892 Electrical Connectors for Use in Battery Powered Ground Support Equipment

2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.2.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

- AIR1363 Four Wheel Drive Aircraft Tow Tractors - Factors for Design Consideration
- ARP1247 Aerospace Ground Support Equipment - General Requirements
- AS1614 Main Line Aircraft Tow Bar Attach Fitting Interface

3. DESIGN FACTORS

The following factors must be considered and evaluated in establishing aircraft tow tractor specifications and design:

3.1 Aircraft Characteristics

- a. Dimensions
- b. Number of landing gears and wheels
- c. Attachment point for towing
- d. Gross weight, empty weight, and weight distribution on the landing gears
- e. Coefficient of breakaway resistance of the aircraft (as a percentage of aircraft weight) for initial motion directed
 1. Straight ahead
 2. In a turn
- f. Coefficient of rolling resistance of the aircraft (as a percentage of aircraft weight) for constant motion on various horizontal surfaces
- g. Turning radius of the aircraft
- h. Angular steering limitation of the aircraft tow fitting
- i. Towing load limitations of the aircraft tow fitting at different directions of towing or pushing
- j. Amount of thrust of engines at idle

The aircraft characteristics are normally provided by the aircraft manufacturer in the Facilities Planning Manual of each particular model of aircraft. The design or specifying engineer must consider all models of aircraft that are to be handled by the tow tractor.

3.2 Airport Conditions

- 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 of ramps, taxiways, runways, and access roads
- e. Road clearance and bridge and overpass limitations
- f. Maximum approach and breakover angles to be negotiated on ramps, taxiways, runways, and access roads
- g. Other towing equipment limitations, physical or regulatory, unique to the local situation



- h. Anticipated towing distances and routes between aircraft maintenance and storage areas and cargo and passenger terminals, etc.
- i. Anticipated daily push-out frequencies and distances by type (weight) of aircraft
- j. Availability of battery charging facilities
- k. Location of battery chargers
- l. Environmental factors and airport surface conditions:
 - 1. Temperature
 - 2. Humidity
 - 3. Altitude
 - 4. Rain
 - 5. Snow or ice
 - 6. Material and condition of airport surface when dry
 - 7. Oil, hydraulic fluid, deicing fluid on airport surface
 - 8. Other pollutants on airport surface

The airport conditions are specified usually by the airlines, ground handling company, or airport authorities user of the tow tractor.

3.3 Tow Vehicle - General Characteristics

- a. Dimensional limitations
- b. Visibility requirements
- c. Operator's compartment location(s)
- d. Speed requirements:
 - 1. Maximum speed - tractor only on level surface
 - 2. Maximum towing speed - tractor and towed aircraft with maximum weight on level surface
- e. Braking capability:
 - 1. Minimum stopping distance at maximum speed - tractor only (or maximum deceleration)
 - 2. Minimum stopping distance at maximum towing speed - tractor and towed aircraft (or maximum deceleration)
 - 3. Emergency braking capability
 - 4. Regenerative braking considerations

- f. Maneuverability requirements and steering capability:
 - 1. Front-wheel steering
 - 2. Four-wheel coordinated steering
 - 3. Two-mode steering: front-wheel and four-wheel coordinated
 - 4. Two-mode steering: four-wheel coordinated and four-wheel crab
 - 5. Three-mode steering: front-wheel, four-wheel coordinated, and four-wheel crab
 - 6. Four-mode steering: front-wheel, rear-wheel, four-wheel coordinated, and four-wheel crab
 - 7. Emergency steering capability
- g. Power train - special requirements about the major components (motor(s), reducer(s), axles, wheels, and tires)
- 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 hitches)
- k. Requirements for ground control communications, including communications between the tow tractor and aircraft
- l. Vehicle lights
- m. Human factor requirements:
 - 1. Environmental protection of operator and passenger(s) (cab)
 - 2. Comfort - location and type of operator's seat, location of controls and instruments, heating and ventilation, operator's compartment lighting, noise level, etc.
 - 3. Safety - access to and from operator's compartment or cab, steps, doors, warning lights and beepers, windshield washer and wipers, visibility to front and rear hitch areas, fire protection, etc.
- n. Special requirements imposed by airport authorities and regulations
- o. Special requirements imposed by the tractor user or buyer
- p. Emergency extraction/towing away/removal of tow tractor and quick release for towbar in case of fire in the tow tractor

The general characteristics of a tow tractor shall be determined so that the vehicle would be able to meet the requirements imposed by the characteristics of the different models of aircraft that will be towed and by the airport conditions where the tractor will operate, providing efficient, safe, and comfortable operation and maintenance.

3.4 Tow Vehicle - Electrical Characteristics

- a. Battery characteristics and battery-related factors (refer to ARP1817):
 - 1. Type: flat plate, tubular plate, lead acid, lithium-ion, etc.
 - 2. Voltage
 - 3. Capacity

4. Access for service, watering, charging
5. Removal and installation provisions
6. Battery layout
7. Battery location and weight distribution
8. Battery management system
9. Battery heating/cooling systems
- b. Type of charger and charger control characteristics (refer to ARP1816):
 1. Communication protocol
- c. Type connectors (refer to ARP1892):
 1. IP grade
- d. Type of drive motor(s) controller:
 1. Vehicle acceleration control
 2. Vehicle forward-reverse motion control
- e. Motor overspeed protection for severe grades
- f. Accessory electric power source:
 1. Converter
 2. Battery
 3. Voltage
- g. Safety devices - seat switches, emergency battery disconnect, driveway interlock, etc.
- h. Waterproofing requirements
- i. Fire suppression requirements

4. PERFORMANCE

4.1 General Notes

During a towing operation, an aircraft tow tractor must be able to overcome all forces resisting the motion of the tow tractor-aircraft train. The power train of the tow vehicle must be able to produce a tractive effort between the tires and airport surface equal to the maximum total resistance, i.e., the maximum amount of all forces resisting the motion of the tractor and aircraft. Since the tractive effort is proportional to the torque on the drive wheel's shaft, the power train of the vehicle must be able to develop the torque required to produce the needed tractive effort. The power train of the tow tractor must also be able to develop enough power to accelerate the tow tractor alone to the specified maximum speed and the tractor-aircraft train to the specified maximum towing speed. On the other hand, the maximum tractive effort that can be developed between the tires and the ground surface is proportional to the weight over the drive wheels. Therefore, a tow tractor must have adequate weight and weight distribution to provide the required maximum tractive effort at specified airport surface conditions.

The braking system of a tow tractor must be able to develop adequate braking force between the vehicle tires and the road surface for a safe braking of the tractor, as well as for a safe braking of the tractor and aircraft. Normally, during a towing operation, only the braking system of the tow tractor is used for braking tow tractor-aircraft train. However, in case of emergency during towing, the tow tractor-aircraft train may be stopped by the aircraft brakes being applied by the captain or braking mechanic of the aircraft. The maximum braking force that can be developed by a tow tractor is proportional to the weight of the tractor. Therefore, the weight of the tractor imposes the major limitations of its braking capability.

The following equations are correct with sufficient approximation at the assumption that an aircraft tow tractor is a relatively heavy, slow-moving, low-profile ground vehicle operating on surfaces with not more than 10% grade. However, it is highly recommended that the specifying or design engineer verify any data and use correct equations depending on the specific type and application of the tow tractor.

For example, the resistance of motion produced by the air is not discussed and included in the provided equations for the total resistance since at low speeds the air resistance is insignificant. However, if the tow tractor moves against strong wind, a significant air resistance is added to all other forces opposing the motion. Therefore, this additional resistance must be considered in the performance calculations.

In this discussion, the weight of the tow vehicle is considered as being equally distributed on the four wheels. For simplicity, the effect of the load transfer, due to the drawbar pull and to the inertial forces during acceleration or deceleration, is neglected as insignificant in establishing the major performance specifications. However, in the detailed calculations and design of the drive system and braking system of the vehicle, the load transfer is one of the major factors for design consideration.

4.2 Resisting Forces

- a. Acceleration Resistance (AR): This is the inertial resistance of the mass of a vehicle to a change in vehicle speed.

The force required to accelerate a vehicle on a level surface from a lower speed to a higher speed is equal to the acceleration resistance of the vehicle.

The tow tractor must overcome the acceleration resistance of the tow tractor-aircraft train. This resistance can be calculated as shown in Equation 1:

$$AR = \frac{(WA+WT) a}{g} \quad (\text{Eq. 1})$$

where:

WA = weight of aircraft

WT = weight of tow tractor

a = acceleration of tow tractor-aircraft train

g = acceleration of gravity (gravitational constant)

In U.S. units, $g = 32.2 \text{ ft/s}^2$

In SI units, $g = 9.81 \text{ m/s}^2$

An acceleration of $a = 0.015 g$ is usually accepted as reasonable considering the limitation of the impact load on the nose gear of the aircraft. At this condition, the acceleration resistance is as follows:

$$AR = 0.015 (WA + WT) \quad (\text{Eq. 2})$$

b. Rolling Resistance (RR): This is a dynamic resistance of the motion resulting from the following:

1. The friction between the tires of a vehicle and the surface on which they roll
2. Deformation of the tires and ground surface
3. Friction in the vehicle wheel bearings

The force required to move a vehicle on a level surface with a constant speed is equal to the rolling resistance of the vehicle.

The tow tractor must overcome the rolling resistance of the tow tractor-aircraft train. This resistance can be calculated as shown in Equation 3:

$$RR = f (WA + WT) \quad (\text{Eq. 3})$$

where:

f = coefficient of rolling resistance

Based on empirical tests, various coefficients of rolling resistance have been established. Usually, the coefficient of rolling resistance is expressed in percent as follows in Table 1:

Table 1

Surface Type	$f\%$ Dry Surface	$f\%$ 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, the coefficient of rolling resistance of an aircraft is usually considered to be 1 to 2% in a straight pull or push and 2 to 4% in a turning maneuver. An average of $f = 2\%$ is considered reasonable for the preliminary calculation of the rolling resistance. Usually, the coefficient of rolling resistance of the tow tractor is accepted to be the same as the coefficient of rolling resistance of the aircraft. Equation 3 is correct at this assumption. At an average $f = 2\%$, the rolling resistance is as shown in Equation 4:

$$RR = 0.02 (WA + WT) \quad (\text{Eq. 4})$$

c. Grade Resistance (GR): This is the components of the vehicle weight acting against the motion when the vehicle moves up a grade.

The tow tractor must overcome the grade resistance of tow tractor-aircraft train when towing an aircraft up a slope. This resisting force can be approximated as shown in Equation 5:

$$GR = G (WA + WT) \quad (\text{Eq. 5})$$

where:

G = grade in percent (ratio of the vertical rise to the horizontal projection of the distance between two points of the ground surface in percent)

An average of 2% grade of the airport surface is considered reasonable for general calculations of the grade resistance. At such assumption, the grade resistance is as shown in Equation 6:

$$GR = 0.02 (WA + WT)$$