

# AEROSPACE INFORMATION REPORT

**SAE AIR4151**

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## Introduction to Starting Systems

### FOREWORD

This SAE Aerospace Information Report (AIR) includes an introduction to the role of a starter, start system types, and some major components. Emphasis is on starting aircraft gas turbine engines used for propulsion, while the concepts generally apply to starting other engines. Other roles the start system may perform are discussed regarding other systems. Cited are some typical start system parameters to acquaint the reader with approximate performance values and to provide some direction toward exploring of a full array of solutions on the way to understanding the operation of engine start systems.

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## SAE AIR4151

### 1. SCOPE:

This SAE Aerospace Information Report (AIR) covers basic aircraft engine start systems fundamentals. It presents various ground power sources and aircraft "on board" starting units. Also included are descriptions of start system components and interconnections which together comprise an engine starting system.

### 2. APPLICABLE DOCUMENTS:

The following publications form a part of this specification 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 specification and references cited herein, the text of this specification takes precedence. Nothing in this specification, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

#### 2.1 SAE Publications:

Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

|         |                                                                                                            |
|---------|------------------------------------------------------------------------------------------------------------|
| AIR744  | Auxiliary Power Sources for Aerospace Applications                                                         |
| AIR713  | Guide for Determining, Presenting, and Substantiating Turbine Engine Starting and Motoring Characteristics |
| ARP906  | Glossary, Aircraft Engine Starting and Auxiliary Power Systems                                             |
| AIR944  | Pneumatic Ground Power Supplies for Starting Aircraft                                                      |
| AIR1174 | Index of Starting System Specifications and Standards                                                      |
| AIR1466 | Hydraulic Energy Limited Engine Starting Systems                                                           |
| AS1606  | Gas Turbine Starter (Jet Fuel Starter) Specification                                                       |
| ARP1961 | Gearbox - Airplane Mounted Accessory, Aerospace                                                            |
| AIR4204 | Commercial Aircraft Auxiliary Power Unit Installation                                                      |

1995 (Annual) SAE Aerospace Standards Index

Rhoden, James A., Modern Technology Secondary Power Systems for Next Generation Aircraft, SAE Technical Paper No. 841606

Anderson, Robert H., Secondary Power Generation System Considerations for Advanced Aircraft, SAE Technical Paper No. 841604

Bellavia, Steven, Influence of Aircraft Systems on Pneumatic Starting, SAE Technical Paper No. 841636

Krochmalny, Andy, Air Turbine Start System for the Next Generation of Large Commercial Aerospace Engines, SAE Technical Paper No. 942106

DeVita, Frank, Synchronous Engagement Clutch, SAE Technical Paper No. 942105

2.1 (Continued):

Krochmalny, Andy, Enhanced Air Turbine Starter Clutch Design, SAE Technical Paper No. 942104

2.2 USAF Publications:

Available from Air Force Wright Aeronautical Laboratories, Wright-Patterson AFB, OH 45433.

Koerner, G.P. and Siddiqui, E.V.A., Permanent Variable Speed Constant Frequency Power Generation System, AFWAL-TR-85-2112

3. DISCUSSION:

3.1 Purpose:

The purpose of the starting system is to reliably and quickly start the propulsion engine(s) of an aircraft. For an understanding we begin with a touch on the theory of starting and follow with a description of system types and finally a description of the components making-up starting systems.

3.2 Starting Energy Balance:

An introduction to a starting system begins with the simple theory of applied rotational torque and its resistance. An aircraft start system provides the main propulsion engine with rotational energy to overcome engine internal friction, pumping losses, and accessory equipment loads. The excess energy, delivered by the start system, accelerates the engine rotor to a speed at which engine light-off can occur and further assist the engine until it reaches idle speed. The energy balance can be stated as shown in Equation 1:

$$T_D = T_a + T_f + T_p + T_s \quad (\text{Eq. 1})$$

where:

$T_D$  = Torque delivered by starter

$T_f$  = Torque to overcome rotor bearing and shaft seal friction

$T_p$  = Torque to move air through the propulsion system (pumping torque)

$T_a$  = Torque to drive engine aircraft accessories (pump(s), generator(s), etc.)

$T_s$  = Torque to increase shaft speed (acceleration)

## 3.2 (Continued):

As propulsion engine speed increases, ignition is turned on and the fuel valve is opened. While the starter still is delivering torque, rotation is assisted by increasing combustion gas expansion in the propulsion engine. This is called transforming from “unfired” to “fired” torque. Self-sustaining speed is when engine turbine work equals compressor work plus any loads and losses. Not all energy released by combustion is available to accelerate the rotor. At this point the mathematical statement becomes as shown in Equation 2:

$$T_D = T_f + T_p + T_a + T_s - T_c \quad (\text{Eq. 2})$$

where:

- $T_D$  = Torque delivered by starter
- $T_f$  = Torque to overcome rotor bearing and shaft seal friction
- $T_p$  = Torque to move air through the propulsion system (pumping torque)
- $T_a$  = Torque to drive engine aircraft accessories (pump(s), generator(s), etc.)
- $T_s$  = Torque to increase shaft speed (acceleration)
- $T_c$  = Applied torque resulting from combustion of fuel

The previous mathematical statement, for a gas turbine propulsion engine, is illustrated in Figure 1.

Note that at some propulsion engine speed greater than zero, the energy released by combustion is exactly equal to that needed to overcome friction, perform pumping, and satisfy accessory needs. At this speed, called the self-sustaining engine speed, there is no excess energy available for acceleration. Therefore, engine developed torque must be starter assisted to further accelerate the engine or to do work external to the propulsion engine system. As a result, the starter must continue to be used to increase engine speed beyond self-sustaining speed.

## 3.3 Start Performance:

Typically, a 111 to 222 kN (25 000 to 50 000 lb) thrust class engine will need 74 kw (100 hp) or more for satisfactory starting. Such a power level will enable start initiation to gas turbine engine light-off to be accomplished in about 10 s on a standard day. The time to reach idle speed can be expected to add another 50 s. Small gas turbine engines are often started over much shorter periods, between 10 to 20 s.

## 3.4 Start System Uses:

Start systems are often used as auxiliary and/or emergency power units both on the ground and in the air. They are equipped with devices capable of providing the electric, pneumatic, and/or hydraulic power needed by other aircraft systems.

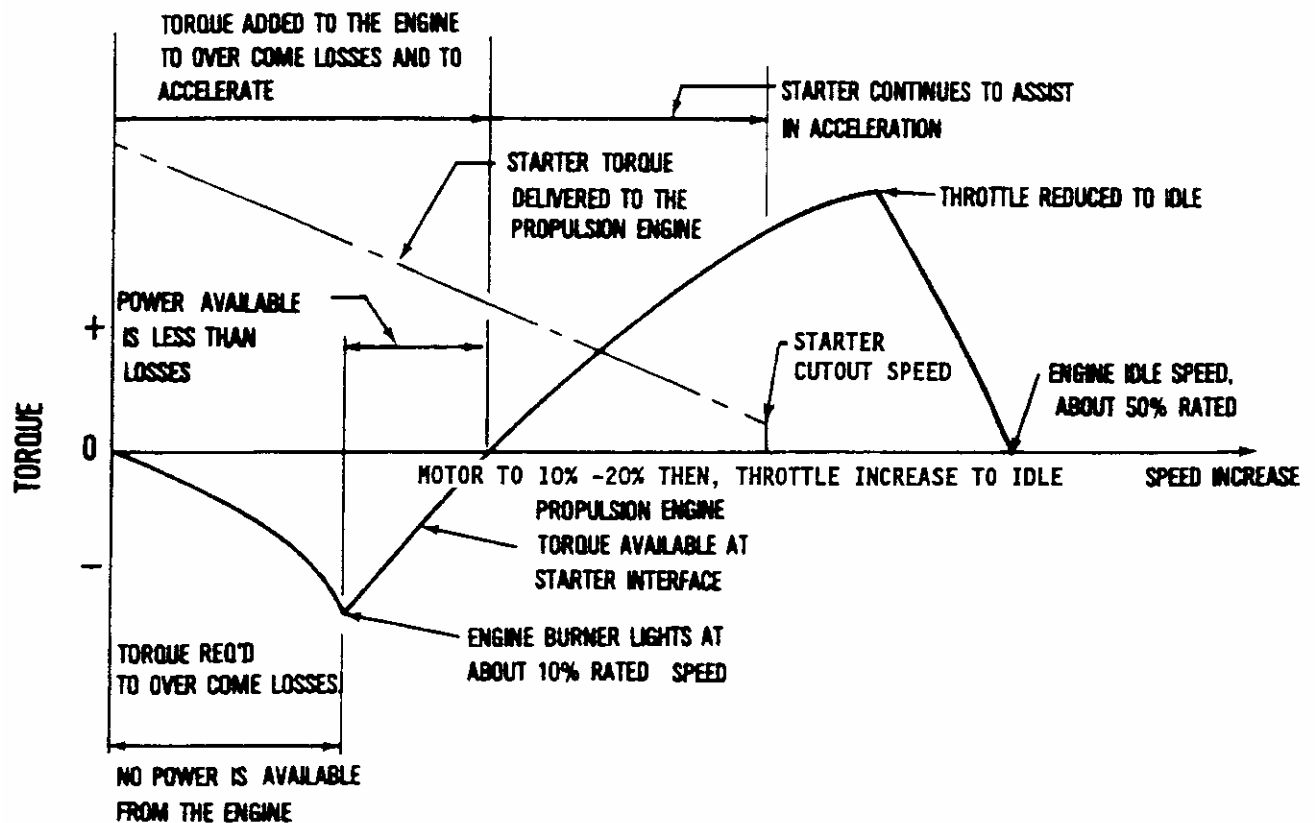


FIGURE 1 - Engine and Starter Torque

## 3.4 (Continued):

Representative power levels provided to a typical wide body transport are about 60 kVA for avionics and other electrical systems, 50 kVA for hydraulics, and 100 kVA for the environmental control system (ECS). The avionics power, in particular, must be of high quality with well controlled voltage and frequency. This additional power generation permits communications, preflight and postflight checkout activities, maintenance, refueling, re-arming, and environmental control needs to be satisfied without operating the propulsion engine(s).

### 3.5 Start System Types:

Start systems are often categorized according to their mobility. There are stationary land based systems, mobile land based systems, and aircraft installed self-contained systems. The first two systems often have one or more start components installed on the engine(s) to be started. In most installations a starter control valve and starter motor are mounted in the aircraft to rotate the propulsion engine.

A system that uses a stationary ground based prime mover is often called a ground power unit (GPU). This may be a facility-installed electric motor or diesel engine. A system that is given ground mobility, usually by means of wheeled chassis, is often called ground support equipment (GSE). A system that has total mobility by virtue of being completely contained in the aircraft is usually called an aircraft power unit or an auxiliary power unit (APU). However, it is not unusual for the term APU to also be applied to relatively small, mobile ground based equipment such as a cart-mounted battery which is almost limited, in practice, to small engine starting (reference ARP906 for additional definitions). As may be expected, there are advantages and disadvantages associated with mobility. While it is difficult to quantify these, even for a specific application, some generalizations may be made.

### 3.6 Ground Power Unit (GPU):

Usually the power provided by a public utility, controlled and distributed via the airport facility, will result in the GPU being the least expensive in terms of dollars per horsepower-hour, or dollars per kilowatt-hour. With relatively few constraints on weight, volume, vibration, etc., the equipment design can emphasize high efficiency. In exchange, the aircraft's position for preflight, postflight, maintenance, and engine starting is sharply constrained by the capacity of the facility and practical limits on hose length and power cable dimensions.

Figure 2 shows a typical installed system that uses 440 V 60 Hz power supplied by a public utility. The 440 V 60 Hz power is converted to aircraft compatible 115/200 V 400 Hz power by means of an electric motor-driven generator. In this example, the power is delivered to the aircraft to support avionics, lighting, propulsion engine starting, and the environmental control system (ECS) which in-turn provides cabin heating and cooling.

Figure 3 shows a facility-installed start system that uses public utility supplied energy, which is in the form of natural gas. In this system, the natural gas powers a diesel engine to produce shaft power. The shaft power may undergo a speed change, through a gearbox, before it is used to drive a 115/200 V 440 Hz generator and in addition, an air compressor to meet aircraft pneumatic needs.

### 3.7 Ground Support Equipment (GSE):

Usually, power made available through mobile GSE will be somewhat more expensive, in terms of dollars per kilowatt-hour, than that provided through a GPU. However, aircraft positioning is a benefit in return. Higher cost can be justified by increased flexibility of vehicle mobility for compatibility with the ramp environment of parking space, noise limits, and the fuel supplied. It is noteworthy that one GSE unit can serve more than one aircraft; but, usually not at the same time during high load conditions such as a propulsion engine start.

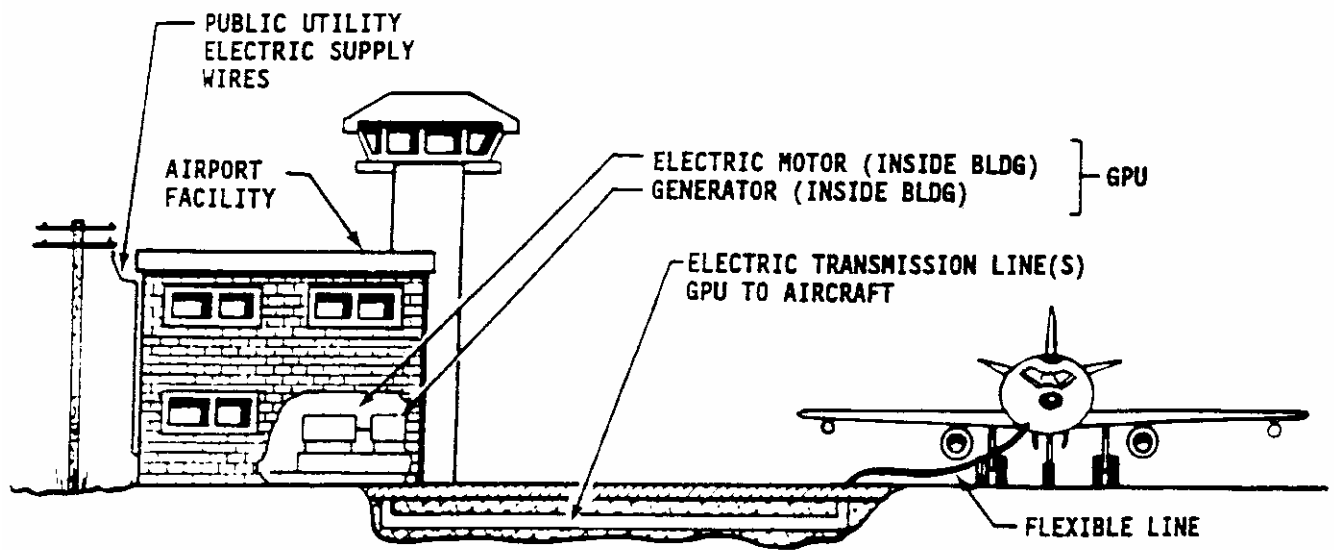


FIGURE 2 - Ground Power Unit (GPU) - Electrical

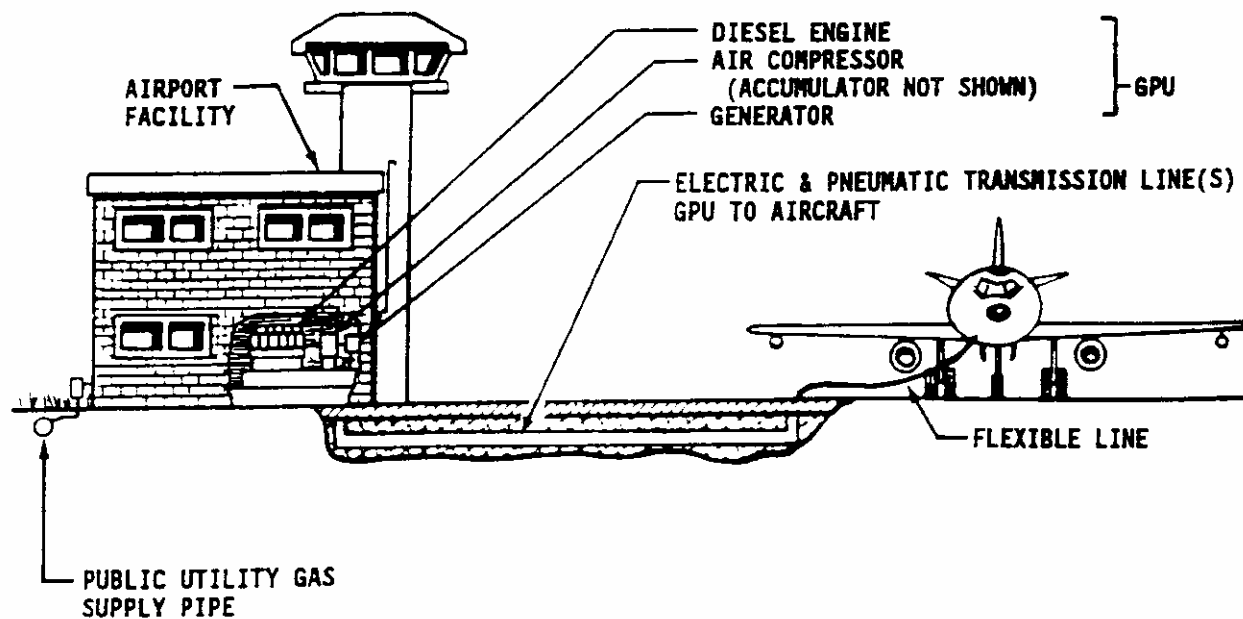


FIGURE 3 - Ground Power Unit (GPU) - Gas

## 3.7 (Continued):

Figure 4 shows a mobile GSE arrangement based upon a small gas turbine engine as a source of air and electric power. The gas turbine engine may have a rating of 149 to 373 kw (200 to 500 hp) and may be installed in a wheeled vehicle for mobility. In this system, a variety of jet engine fuels can be used by the small engine to produce shaft horsepower. Typical fuel consumption rates vary from about 0.91 kg/kw-h (1.5 lb/hp-h) for the smaller gas turbine engines to about 0.36 kg/kw-h (0.6 lb/hp-h) for the larger engines. The shaft power (often provided via a gearbox), is used to drive a 115/200 V 440 Hz generator and an air compressor. The air compressor may be a reciprocating, rotary, screw, or centrifugal design. Additional pneumatic requirements can be met by extracting air directly from the compressor on the small gas turbine engine. On the other hand, the separate air compressor permits the small engine's compressor design to realize lower fuel consumption. The separate compressor called a "load compressor" can be operated at an environmental control system (ECS) compatible pressure ratio of about five for inlet to outlet pressure while the GPU engine's compressor may operate at a pressure ratio of about eight.

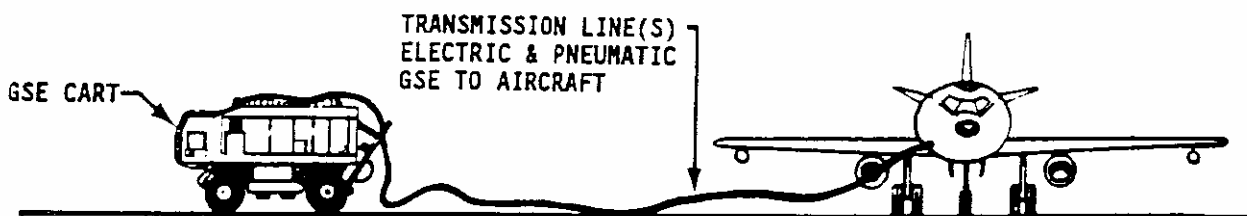


FIGURE 4 - Ground Support Equipment (GSE)

A diesel or spark ignition engine may be substituted for the small gas turbine engine if a separate compressor is used. The choice of a prime mover is often a diesel since it offers low fuel consumption of less than 0.24 kg/kw-h (0.4 lb/hp-h). If a low temperature start, in less than 30 s time is necessary the usual choice is a gas turbine. Spark ignition engines, seldom used for aircraft applications at this time, are somewhere between the other two types in fuel consumption in low temperature start capability, weight, and envelope volume. Many other factors influence the selection of a GPU engine.