

**GUIDE FOR DETERMINING, PRESENTING, AND SUBSTANTIATING
TURBINE ENGINE STARTING AND MOTORING CHARACTERISTICS**

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Revised

1. PURPOSE - The purpose of this information report is to provide a general guide for determining, presenting, and substantiating turbine engine starting and motoring characteristics.
2. SCOPE - This information report includes procedures for determining and presenting in standard form and terminology turbine engine starting and motoring characteristics. It further includes the requirement for substantiating the accuracy of the information presented.
3. DETERMINATION OF ENGINE STARTING AND MOTORING CHARACTERISTICS - The primary method of determining engine starting and motoring characteristics should be by testing of a complete engine and calculating the required information from the test data. Empirical, theoretical, or other means should be used when the information is required for a nonexistent engine.
 - 3.1 Engine Testing
 - 3.1.1 Testing Techniques
 - 3.1.1.1 Test Equipment
 - 3.1.1.1.1 Engine - The test engine should be a production unit or be functionally identical to a production unit. It is preferable that the engine be at or near specification performance. In any event the performance level of the engine to be tested should be established.
 - 3.1.1.1.2 Engine Accessories - The test engine should include all units which are considered permanent engine accessories. Accessories which must be used during the test but which will not be a part of the installation furnished by the engine manufacturer to the customer should be noted so that their effect on engine starting characteristics may be removed from the performance presented to the customer.
 - 3.1.1.1.3 Engine Fuel Supply - The test engine fuel supply should utilize a type of fuel, fuel temperature, and fuel pressure established by the engine and fuel specifications.
 - 3.1.1.1.4 Engine Starter - The engine starter may be any type selected by the engine manufacturer but should be capable of supplying torque levels covering the full range permitted by the engine.
 - 3.1.1.1.5 Engine Lubricant - The test engine lubricant should be of the type specified in the applicable engine model specification.
 - 3.1.1.2 Instrumentation
 - 3.1.1.2.1 Engine

- 3.1.1.2.1.1 Engine Rotor Speed - The engine rotor speed should be measured at the engine starter drive or equivalent and should be recorded as a function of time except during motoring operation.
- 3.1.1.2.1.2 Engine Combustion Temperature - The engine combustion temperature should be measured at the turbine inlet or at the turbine exhaust, according to the engine manufacturer's normal procedures, and should be recorded as a function of time.
- 3.1.1.2.1.3 Fuel Supply Temperature - The engine fuel supply temperature should be measured at the engine fuel supply connection and also as close as possible to the engine fuel manifold.
- 3.1.1.2.1.4 Fuel Supply Pressure - The engine fuel supply pressure should be measured at the engine fuel supply connection and should be recorded as a function of time.
- 3.1.1.2.1.5 Inlet Air Temperature - The engine inlet air total temperature should be measured at the compressor inlet face and should be recorded as a function of time.
- 3.1.1.2.1.6 Inlet Air Total Pressure - The engine inlet air total pressure should be measured at a point representative of the total pressure at the compressor face and should be recorded as a function of time.
- 3.1.1.2.1.7 Exhaust Nozzle Static Pressure - The engine exhaust nozzle static pressure should be measured in the plane of the nozzle exit. It should be recorded as a function of time. An effort should be made to establish the exhaust static pressure equal to the compressor inlet total pressure.
- 3.1.1.2.2 Starter
- 3.1.1.2.2.1 Starter Output Torque - The starter output torque should be determined with a torque measuring device or by use of a starter previously calibrated in terms of input and output conditions. Starter performance should be recorded as a function of time during engine starting tests and as a function of speed during engine motoring tests. Starter torque obtained on a transient basis should be corrected for effects of starter inertia to obtain steady state performance.
- 3.1.1.2.2.2 Start Initiation - The point at which the starter is energized should be indicated on the engine rotor speed time scale.
- 3.1.1.2.2.3 Starter Cutoff - The point at which the starter cuts off should be indicated on the engine rotor speed time scale.

3.1.1.3 Test Variables and Range

3.1.1.3.1 Ambient Conditions

- 3.1.1.3.1.1 Engine Inlet Air Temperature - The total temperature of the air at the engine compressor face represents the ambient temperature in which the engine is being started. This ambient temperature should cover the normal operating range of the engine. At least three temperatures should be used which should include the maximum and minimum at which the engine is rated and a standard day condition.
- 3.1.1.3.1.2 Engine Exhaust Air Pressure - The static pressure at the engine exhaust nozzle represents the ambient pressure at which the engine is being started. The ambient pressure may be that existing at the test facility altitude.

3.1.1.3.2 Engine

- 3.1.1.3.2.1 Engine Fuel Supply Temperature - The engine fuel supply temperature should be within 5 F of the ambient air temperature or should be at the limit fuel temperature as determined by consideration of both the engine and fuel specifications.

- 3.1.1.3.2.2 Engine Fuel Supply Pressure - The engine fuel supply pressure during the start should be within the limits established by the engine and fuel specifications.

3.1.1.3.3 Starter

- 3.1.1.3.3.1 Starter Output Torque - The starter output torque characteristic is established by the type of starter and by the energy level supplied to the starter inlet. During the starting tests the starter should utilize at least three levels of output torque covering the full range permitted by the engine. During the motoring tests the starter should utilize as many steady state output torque levels as are required to obtain a continuous set of data points from zero to the highest speed obtainable with engine fuel and ignition off.

- 3.1.1.3.3.2 Starter Cutoff Speed - The starter cutoff speed should be within the limits specified by the engine manufacturer.

3.1.1.3.4 Start and Restart Effects

- 3.1.1.3.4.1 Initial Starts - The tests should include initial starts at each ambient temperature. An initial start is encountered after an approximately eight-hour soak at the test ambient temperature of a shut-down engine.

- 3.1.1.3.4.2 Restarts - The tests should include restarts at each ambient temperature. Consideration should be given to factors of time, temperature and power level in determining the most critical restart conditions.

3.1.1.4 Operational Considerations

3.1.1.4.1 Test Configuration - The test configuration should consist of those items listed in 3.1.1.1 of this document.

3.1.1.4.2 Engine Preparation - The proper engine preparation prior to a start should be specified in detail.

3.1.1.4.3 Engine Starting Procedure - The engine manufacturer's recommended starting procedure for production engines should be followed.

3.1.2 Torque Calculation

3.1.2.1 Starter Data Required

3.1.2.1.1 Effective Polar Moment of Inertia - The effective polar moment of inertia of the starter rotating parts at the starter drive should be obtained from the starter manufacturer.

3.1.2.1.2 Starter Output Torque - The steady state starter output torque should be plotted as a function of starter drive speed from data obtained under items 3.1.1.2.1.1 and 3.1.1.2.2.1. This information should be plotted as shown in Figure 1 for each test condition.

3.1.2.2 Engine Data Required

3.1.2.2.1 Effective Polar Moment of Inertia - The effective polar moment of inertia of the starter driven rotating parts should be determined and specified in terms of the starter drive speed. It should include all rotating parts such as pumps and other accessories exclusive of the starter. For starter driven propellers the polar moment of inertia of the propeller and the rotating parts of its reduction gearing should be included.

3.1.2.2.2 Engine Rotor Speed - The engine rotor speed as measured at the starter drive should be plotted as a function of time as shown in Figure 2. Inasmuch as the accuracy of the calculations depends upon having a well-defined curve form, any oscillatory displacements impressed upon the curve by engine vibration or instrumentation techniques should be removed prior to plotting the data.

3.1.2.3 Other Information Required

3.1.2.3.1 Engine Lightoff Speed - The engine lightoff speed should be shown on Figure 2.

3.1.2.3.2 Starter Cutoff Speed - The starter cutoff speed should be shown on Figure 2.

3.1.2.3.3 Engine Idle Speed - The point at which the engine attains idle speed should be shown on Figure 2.

3.1.2.3.4 Starter Drive Gear Ratio

3.1.2.3.5 Maximum Allowable Continuous Torque at the Starter Drive

3.1.2.3.6 Maximum Allowable Static Torque at the Starter Drive

3.1.2.3.7 Propeller Gear Ratio (for starter driven propellers)

3.1.2.4 Calculation Procedure

- 3.1.2.4.1 Effective Polar Moment of Inertia - The effective polar moment of inertia of the starter ($I_{st. eff.}$) is the actual moment of inertia of its rotating parts referred to the starter drive.

The effective polar moment of inertia of the engine is the sum of the actual moments of inertia of all of its rotating parts referred to the starter drive. If the moments of inertia of the engine components are specified at their own shafts, the effective polar moment of inertia at the starter drive may be obtained in the following manner:

$$I_{eng. eff.} = (I_{eng.} + I_{access.} \times G.R._{access.}^2) / G.R._{st. drive}^2$$

where

$I_{eng. eff.}$ = effective polar moment of inertia of all of the engine rotating parts including accessories exclusive of the starter referred to the starter drive.

$I_{eng.}$ = actual polar moment of inertia of the engine only at the engine motor.

$I_{access.}$ = actual polar moment of inertia of each accessory at its own shaft.

$G.R.$ = gear ratio referred to main engine rotor.

- 3.1.2.4.2 Acceleration Torque - The acceleration torque is the net torque available for accelerating the engine and accessories including the starter when engaged. It is the algebraic sum of the starter, engine, and accessory torques. Drag torques representing energy absorbed by a unit are negative values.

Torques contributing to the rotation of the components are positive values. Prior to engine lightoff the engine and accessory torques subtract from the torque available from the starter for acceleration by an amount equal to their drag torques. After lightoff the engine torque soon becomes positive beyond which point the engine torque contributes to acceleration. The acceleration torque may be computed from the starter drive speed vs. time curve, shown in Figure 2, and from the effective polar moments of inertia of the starter and engine with accessories included by means of the following equation:

$$T_{\text{accel.}} = \frac{\pi}{30} (I_{\text{st. eff.}} + I_{\text{eng. eff.}}) \times \frac{\Delta N}{\Delta t}$$

(For disengaging type starters only $I_{\text{st. eff.}} = 0$ after cutoff)

where

$T_{\text{accel.}}$ = net acceleration torque at starter drive = lb. ft.

I = effective polar moments of inertia as defined in 3.1.2.4.1 — lb. ft. sec.²

ΔN = speed increment — rpm

Δt = time increment during speed increment ΔN — seconds

$\frac{\Delta N}{\Delta t}$ = slope of the engine speed vs. time curve at a given speed — rpm/second

3.1.2.4.3 Engine Starting Torque - The engine starting torque may be obtained from the acceleration torque of item 3.1.2.4.2, the starter torque of item 3.1.2.1.2, and any torques for accessories not a part of the engine installation but included as test equipment as discussed in item 3.1.1.1.2 from the following equation:

$$T_{\text{eng.}} = T_{\text{accel.}} - T_{\text{st.}} + T_{\text{access.}}$$

where

$T_{\text{eng.}}$ = engine starting torque — lb. ft.

$T_{\text{accel.}}$ = net acceleration torque — lb. ft.

$T_{\text{st.}}$ = steady state starter torque — lb. ft.

$T_{\text{access.}}$ = transient accessory drag torque — lb. ft.

3.1.2.4.4 Methods of Solution - The equations of items 3.1.2.4.2 and 3.1.2.4.3 may be solved by tabular, graphical, or computer methods. In each case the increments of rpm selected should be small to maintain accuracy.

3.2 Empirical - Empirical methods of determining engine starting and motoring characteristics should be used when the specific type of engine is not available for testing. These methods include scaling by interpolation or extrapolation of information obtained from testing of other engines or components.

- 3.3 Theoretical - Theoretical methods of determining engine starting and motoring characteristics should be used when the specific type of engine is not available for testing and information for development of empirical data is unavailable. These methods include basic thermodynamic and aerodynamic relationships.
- 3.4 Other Methods - A combination of the above or other methods available to the engine manufacturer should be used to obtain the best possible data for presentation.

4. PRESENTATION OF ENGINE STARTING AND MOTORING CHARACTERISTICS

4.1 Data to be Presented

4.1.1 Variable Parameters

4.1.1.1 Engine Starting Torque vs. Starter Drive Speed

4.1.1.1.1 Effect of Starter Torque - The engine starting torque should be presented for three steady state starter torque levels unless the engine starting tests show that no significant differences in engine starting torques exist. The starter torque levels should cover the full range of torques acceptable to the engine.

4.1.1.1.2 Effect of Ambient Temperature - The engine starting torque should be presented for at least three ambient temperatures including the highest and lowest ambients for which the engine may be started. The third temperature should be a standard day condition.

4.1.1.1.3 Effect of Altitude - The performance curves should include a means of correcting engine starting torques for altitudes up to 15,000 feet.

4.1.1.2 Engine Lightoff Speed

4.1.1.2.1 Effect of Starter Torque - The point at which engine lightoff occurs should be shown for each starter torque level.

4.1.1.2.2 Effect of Ambient Temperature - The effect of ambient temperature on the lightoff speed at the maximum and minimum temperatures for which the engine is designed should be shown if significant.

4.1.1.2.3 Effect of Altitude - The effect of altitude up to 15,000 feet on engine lightoff speed should be indicated if significant.

4.1.1.3 Engine Motoring Torque vs. Starter Drive Speed - The engine motoring torque should be presented versus starter drive speed covering the rpm range specified in 3.1.1.3.3.1. Effects of ambient temperature should be shown covering the temperature range specified in 4.1.1.1.2. Effects of altitude should be shown covering the altitude range specified in 4.1.1.1.3.

4.1.2 Fixed Parameters - The fixed parameters are those items which do not vary during the course of the engine start. These include items which are established by the engine manufacturer to protect the engine as well as certain details of the engine configuration.

4.1.2.1 Maximum and Minimum Time to Engine Lightoff

4.1.2.2 Maximum and Minimum Time from Lightoff to Cutoff

4.1.2.3 Minimum Starter Torque at Breakaway, Lightoff, and Cutoff

4.1.2.4 Maximum and Minimum Starter Cutoff Speeds

4.1.2.5 Maximum Continuous Applied Torque at Starter Drive

4.1.2.6 Maximum Static Applied Torque at Starter Drive

4.1.2.7 Engine Idle Speed

4.1.2.8 Minimum Recommended Engine Motoring Speed

4.1.2.9 Critical Engine Motoring Speeds

4.1.2.10 Starter Drive Gear Ratio

4.1.2.11 Effective Polar Moment of Inertia of the Engine Rotating Parts at the Starter Drive

4.1.2.12 Torsional Stiffness and Angular Backlash of the Starter Drive

4.1.2.13 Engine Fuel Used

4.1.2.14 Starter Drive AMD Specification and Direction of Rotation

4.1.2.15 Maximum Engine Overspeed

4.1.2.16 Lubricant Type and Viscosity

4.1.2.17 Conditions Prior to Start - This includes the conditions which define an initial start or a restart as listed in 3.1.1.3.4.

4.2 Form of Data Presentation

4.2.1 Variable Parameters

4.2.1.1 Engine Starting Torque vs. Starter Drive Speed - The engine starting torque requirements as specified in items 4.1.1.1 and 4.1.1.2 should be presented as a function of starter drive speed as shown in Figure 3. A separate curve sheet for each ambient temperature at sea level altitude should be provided.

- 4.2.1.2 Engine Motoring Torque vs. Starter Drive Speed - The engine motoring torque requirements as specified in item 4.1.1.3 should be presented as a function of starter drive speed as shown in Figure 4.
- 4.2.2 Fixed Parameters - Items 4.1.2.3, 4.1.2.4, 4.1.2.7, 4.1.2.13, 4.1.2.16, and 4.1.2.17 should be included on Figure 3. Items 4.1.2.8, 4.1.2.9, and 4.1.2.16 should be included on Figure 4. All other items under 4.1.2 may be shown on these figures or, if not, should be shown on separate data sheet (see Table I).
5. SUBSTANTIATION OF ENGINE STARTING AND MOTORING CHARACTERISTICS - The source of information should be indicated where applicable for each item of data under 4.1. Information should be given as to whether the data were determined by test, empirical, theoretical, or other means. With this information, the user will have a rational basis for design of the engine starting system.

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STEADY STATE STARTER TORQUE VERSUS SPEED

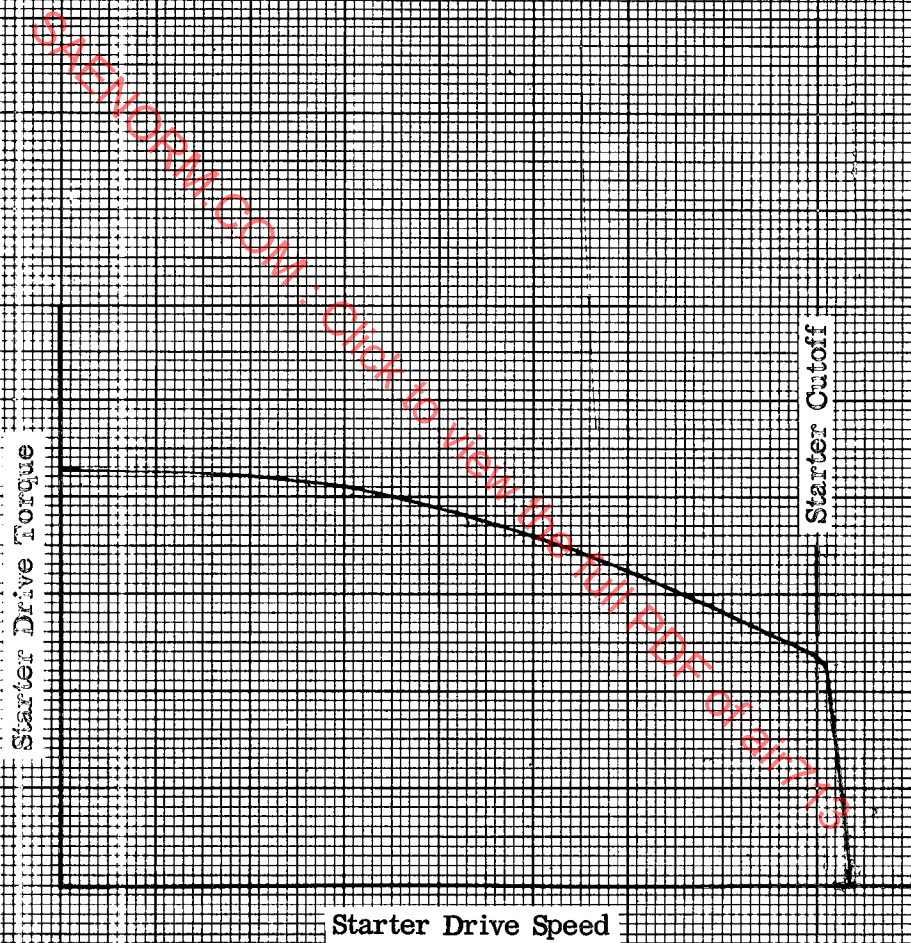


Figure 1

STARTING SPEED VERSUS TIME

Note: Accurate account must be taken of change in curve shape at points such as engine lightoff and starter cutoff.

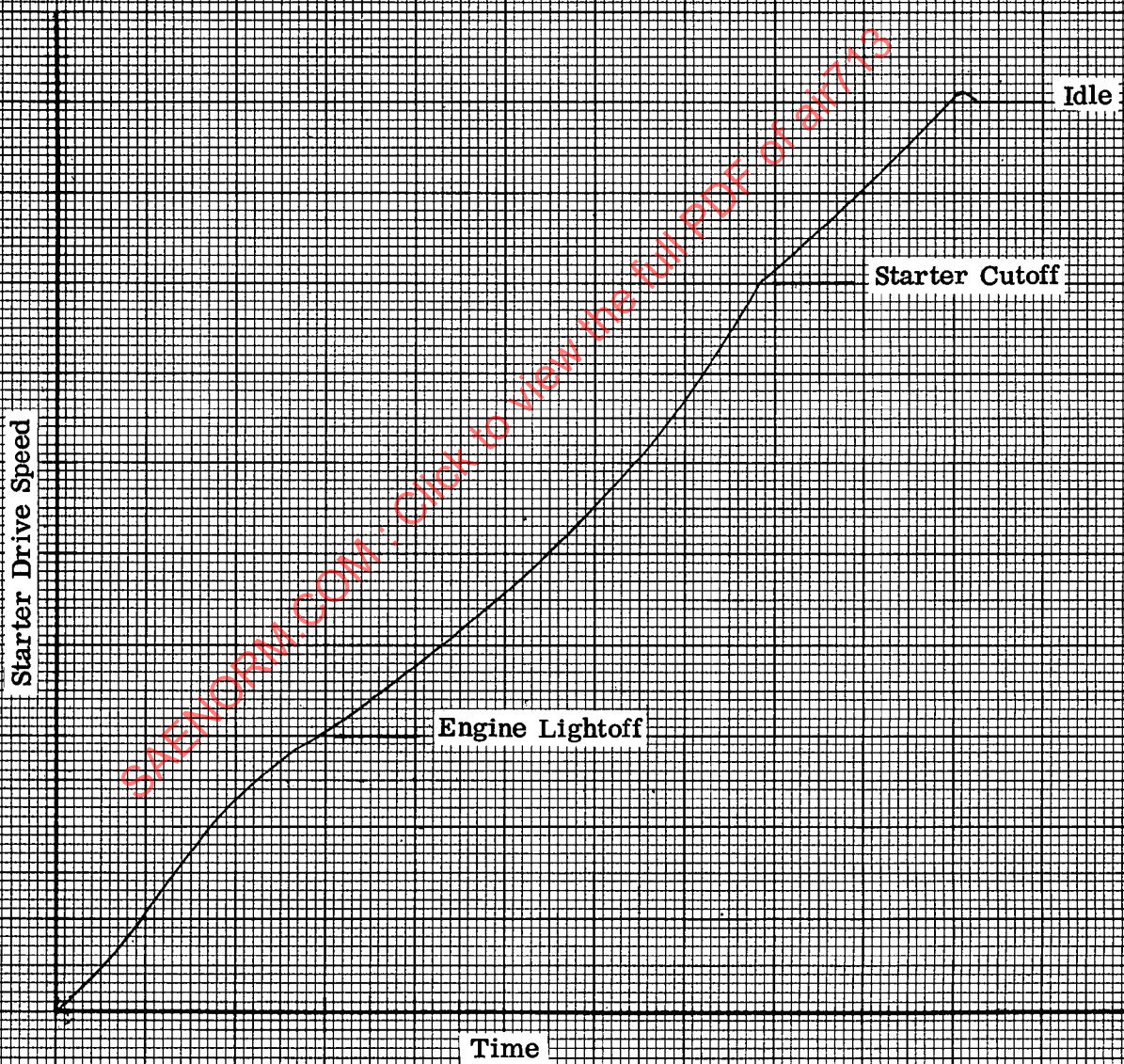


Figure 2