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AEROSPACE RECOMMENDED PRACTICE

ARP 949A
Superseding ARP 949

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TURBINE ENGINE STARTING SYSTEM DESIGN REQUIREMENTS

1. PURPOSE: This recommended practice is intended to define and establish, where applicable, a standard presentation of the engine characteristics required for the determination of a satisfactory starting system for aircraft gas turbine engines.

2. DISCUSSION: A satisfactory starting system is defined as that system which will assure acceleration from zero rpm (+___ rpm -___ rpm to account for a decelerating engine or an engine windmilling in the reverse direction of rotation) for ground starts, or windmill speed for inflight starts, to idle speeds within established limits for the engine or other starting system components for all required conditions.

3. REQUIREMENTS: To insure a satisfactory starting system design, the engine characteristics, as well as anticipated operating limitations, must be defined in detail. If at the end of the design process, other operational restrictions are determined, these restrictions should be included in the engine characteristics. Wherever applicable, the basis for performance estimates should be indicated as being determined empirically or theoretically. These characteristics and limitations include the following:

3.1 Engine Supplied Torque: Engine supplied torque shall be defined as unfired and fired torque in sufficient detail as to clearly describe the effects of ambient temperature, altitude, ram pressure ratio (flight speed), engine acceleration rate, customer compressor bleed, and customer power extraction as applicable to the particular application. The effects of engine required compressor bleed and power extraction shall be included in the basic engine torque. Figure 1 shows the unfired and fired torque characteristics versus starter drive speed at sea level static, with zero customer mechanical or pneumatic power extraction, for cold, standard, and hot ambient temperatures.

The engine torque characteristics as modified for the altitude effect shall be presented in the format of Figure 1 or 2 with the altitude and temperature noted. The torque characteristics may be defined at as many altitudes as required for the particular application.

3.1 (Continued):

Figure 3 presents the pneumatic power extraction torque correction to be applied algebraically to the engine torques of Figure 1 to determine the net engine torque. If required, additional corrections may be supplied to define these characteristics as a function of altitude.

Customer accessory power extraction (torque) applied to the engine for accessories or functions not included in the engine-supplied torque curve should be added algebraically to the engine-supplied torque curve.

Figure 4 shows the engine torque versus speed as a function of ram pressure ratio or flight speed at a particular altitude. This figure can be repeated at selected altitudes to describe the engine inflight starting torques throughout the inflight starting envelope.

The engine inflight starting envelope should be shown as in Figure 5.

3.2 <u>Light-Off Characteristics</u>: Light-off characteristics are defined to establish the engine speed range in which 1) turbine temperature transients are within acceptable limits, and 2) the required fuel/air ratios for reliable light-offs are present. The light-off characteristics may vary with altitude, ambient temperature, acceleration rate, starting procedure, etc., and if so, must be defined as a function of the particular variables. These expressions are too varied to delineate in detail and only three representative examples are indicated:

1) Light-off speed greater than ___ percent speed. This expression is valid to protect the turbine from light-off transients and in those cases where no upper limit is required.

2) Light-off speed greater than ___ percent and less than ___ percent speed. This expression illustrates the case in which the lower speed is utilized to protect the turbine from light-off transients as in 1), but imposes an upper limit to insure a proper fuel/air ratio for ignition.

3) Light off occurs ___ seconds after fuel on at ___ percent speed. This expression is used when a particular start procedure is specified and describes the fuel and ignition characteristics when using the procedure.

4) Altitude effects can be expressed by varying the minimum and maximum idle speeds, the speed at which fuel and ignition are applied, plus the time required for ignition delay, if applicable.

5) Automatic relight functions can be established to provide re-start initiation when, for a given power lever angle 1) engine speed drops below a specified level, or 2) the measured exhaust gas temperature (EGT) drops below the scheduled EGT by a predetermined rate.

3.3 Hot Section Parts Exposure to Starting Temperatures: The time duration of the exposure of the hot section parts to starting temperatures is a function of the acceleration rate from light-off to idle speed. If required for engine protection and/or life, the minimum acceleration (torque) must be defined over the applicable speed range and climatic conditions, such as ambient temperature, altitude, and/or wind conditions. These torques represent net torques which provide a minimum acceleration rate that is the algebraic sum of engine, accessories, and starter torques. These may be a constant value or may vary with engine speed over a specified speed range.

3.4 Crosswind and Tailwind Limitations: Limitations imposed by wind direction and/or velocity may have an adverse effect upon the starting characteristics, particularly engine torque, turbine temperatures, and light-off characteristics. Limitations evolving from the wind effects and corrective measures, when required, must be defined for the particular application.

The limitations may be expressed as simple statement, such as: "Normal starts may be accomplished for crosswind and tailwinds up to ___ knots. For wind velocities greater than ___ knots, special start procedures must be used."

The limitations may be expressed in graphical form, as shown on Figure 6, when the effect upon starting performance varies with the direction and velocity of the wind.

3.5 Windmill Power Extraction: The mechanical power extraction capability shall be defined at the specified flight conditions as required by the particular application. These data are required to define emergency power generation, either electrical or hydraulic, and to provide the basis for accessory load effects on windmill starting.

Figure 7 illustrates the presentation of these data as a function of flight speed or Mach number over the applicable engine inlet pressure range. Additional data may be required for cases where the corrected torque varies significantly with altitude or ambient temperatures. These data may be presented at the several altitudes and/or ambient temperatures which will define the engine capability over the inflight starting envelope.

3.6 Engine Idle Speeds: Engine idle speeds are to be defined 1) to specify the termination point or points of the start, 2) to insure no interference with the operational use of aircraft accessories, and 3) to provide a limit for defining starter cutout speed. Idle speed may be defined as simple statements of either physical or temperature corrected speed, or if idle speed is continuously variable with ambient temperature or altitude, a graphical presentation as shown in Figure 8 may be used.

3.7 Starter Cutout Speed: Starter cutout speed is established at a speed less than idle speed and above the speed where engine start acceleration torque exceeds drag and the engine becomes self-sustaining. Minimum starter cutout speed may be defined as a function of engine speed, such as ___ rpm greater than self-sustaining speed, or as that speed which provided ___ lb-ft net accelerating torque from the engine.

3.8 Starter Re-engagement Speeds: Re-engagements by the starter may be required to provide engine assist for motoring (to cool a hot engine, or purge an engine of unlit gases), or re-starting an engine while it is spooling down or windmilling (during flight). The windmilling speed, and maximum re-engagement speed shall be defined. Refer to Figure 5 for a definition of engine relight envelope where starter assist is required. The windmilling speed shall be estimated; or measured where flight data is available.

3.9 Starter Impact Torque: Re-engagements by the starter cause impact torques to be imposed on the engine drive train, and therefore, needs to be considered for design purposes. The maximum instantaneous impact torque limitation shall be established for this purpose. The engine data required to calculate the impact torque are listed in Paragraph 3.11 below. The method of calculating impact torque may be found in AIR 781, Guide for Determining Engine Starter Drive Torque Requirements. The possibility of a starter "crash engagement" shall be considered in determining the starter drive torque limitation. It may be desirable to incorporate a shear section in the engine drive pad or specify one for the starter to prevent damage to the engine drive train. The maximum rotor speed for re-initiation of cranking (re-engagement) shall be established to avoid engine or starter damage.

(A "crash engagement" can occur due to system malfunction where after a start is made, and the starter centrifugal clutch has disengaged, the air to the starter is left on allowing the starter to operate at no load free run speed; then when the engine is shut down, the clutch portion of the starter being driven by the engine will attempt to re-engage at its reset speed, but with the starter input portion of the clutch operating at a very high speed, a "crash engagement" takes place, causing a very high impact torque which usually damages the starter.)

3.10 Maximum Starter Pad Speed: The maximum starter pad speed at 100 percent engine speed shall be defined to allow the starter manufacturer to design the starter overrunning mechanism to ensure starter integrity, and to analyze failure modes in the event of a component malfunction such as failure of the cutout switch to actuate, or failure of the engaging mechanism to disengage.

3.11 Engine Structural and Rotating Component Characteristics: These characteristics shall include:

1) Mass polar moment of inertia of engine rotating parts at the starter drive, ___ slug-ft^2.

2) Gear ratio, starter drive speed/engine rotor speed, ___.

3) Maximum torsional stiffness of the rotating engine parts, ___ lb-ft/radian at the starter drive.

4) Maximum backlash of the rotating engine parts, ___ radians at the starter drive.

5) Maximum instantaneous torsional limit of starter drive ___ lb-ft.

6) Maximum continuous starter torque limit ___ lb-ft.

7) Maximum starter drive speed for re-engagement ___ rpm.

8) Starter drive pad configuration and direction of rotation.

9) Engine lubricant designation.

10) Engine fuel designation and limits, imposed, if any.

11) Engine 100 percent rotor speed referred to the starter drive pad.

3.12 Shutdown Procedures: Requirements to use the starting system during engine shutdown, cooling, or purging should be specified as to minimum or maximum speed, time duration, or whatever other limits are to be observed.

3.13 Related SAE Start System Reference Documents:

1. AIR 781, Guide for Determining Engine Starter Drive Torque Requirements.

2. AS 972B, Spline Details, Accessory Drives and Flanges.

3. AIR 713A, Guide for Determining, Presenting, and Substantiating Turbine Engine Starting and Motoring Characteristics.

4. ARP 906, Glossary, Aircraft Engine Starting and Secondary Power Systems.

5. AIR 1087, Aircraft Accessory Drag Torque Druing Engine Starts.

6. AIR 1639, Safety Criteria for Pneumatic Starting Systems.

3.13 (Continued):

7. AIR 1467, Gas Energy Limited Starting Systems.

8. AIR 1174, Index of Starting System Specifications and Standards.

9. AIR 1466, Hydraulic Energy Limited Starting Systems.

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STARTING SYSTEMS

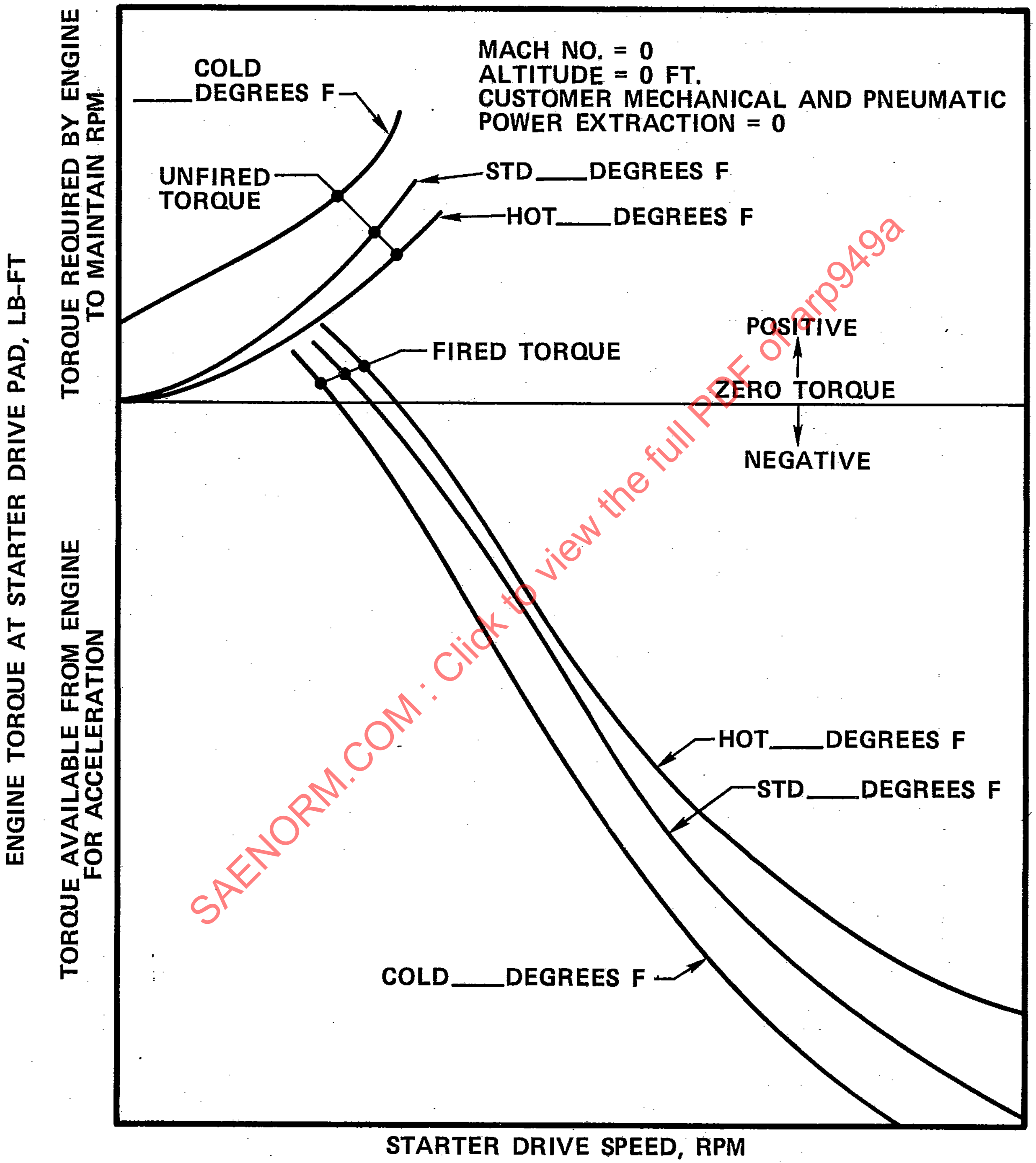

FIGURE 1

FIRED AND UNFIRED ENGINE TORQUE CHARACTERISTICS AND EFFECT OF AMBIENT TEMPERATURE

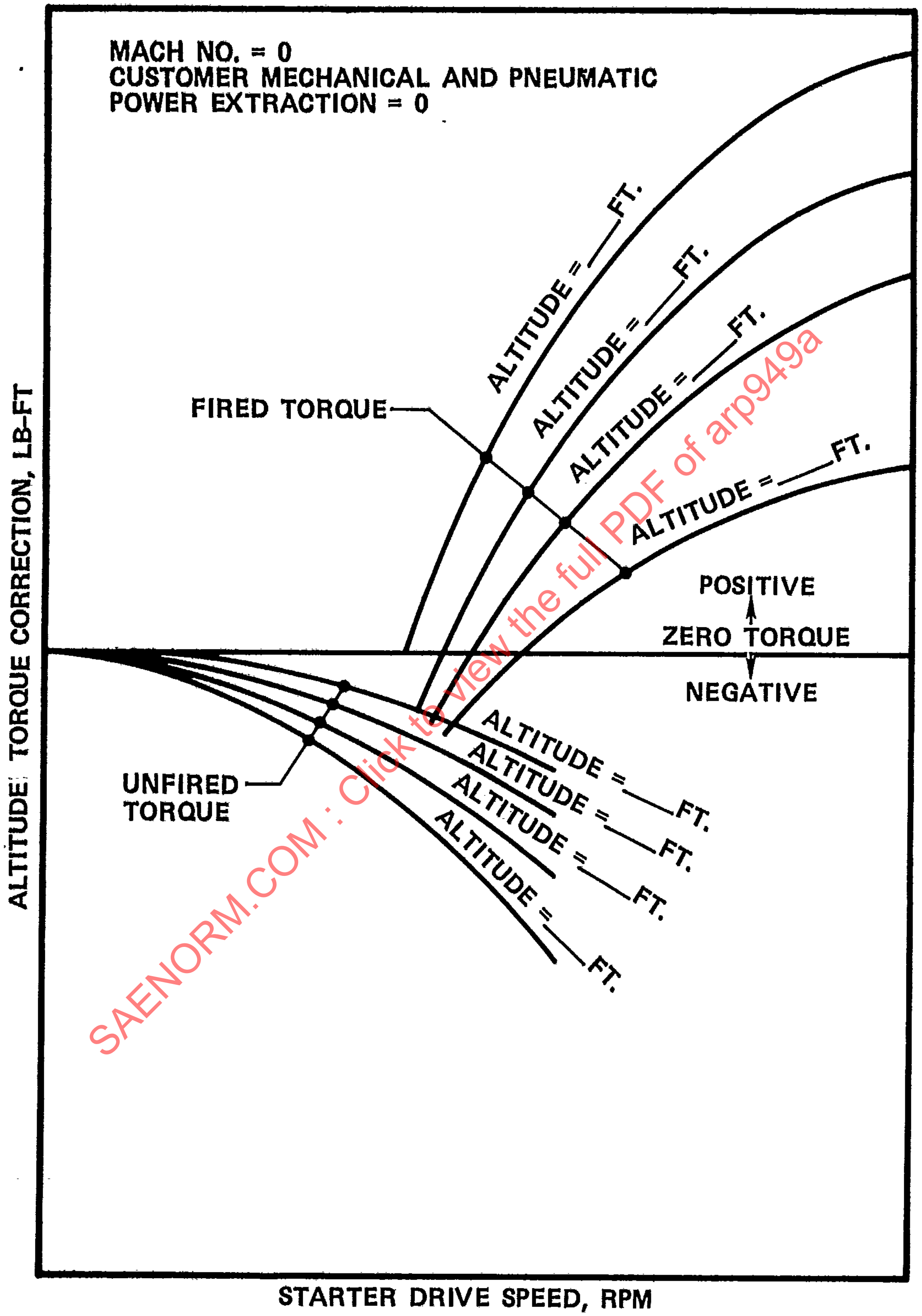

FIGURE 2

EFFECT OF ALTITUDE ON THE ENGINE TORQUE CHARACTERISTICS

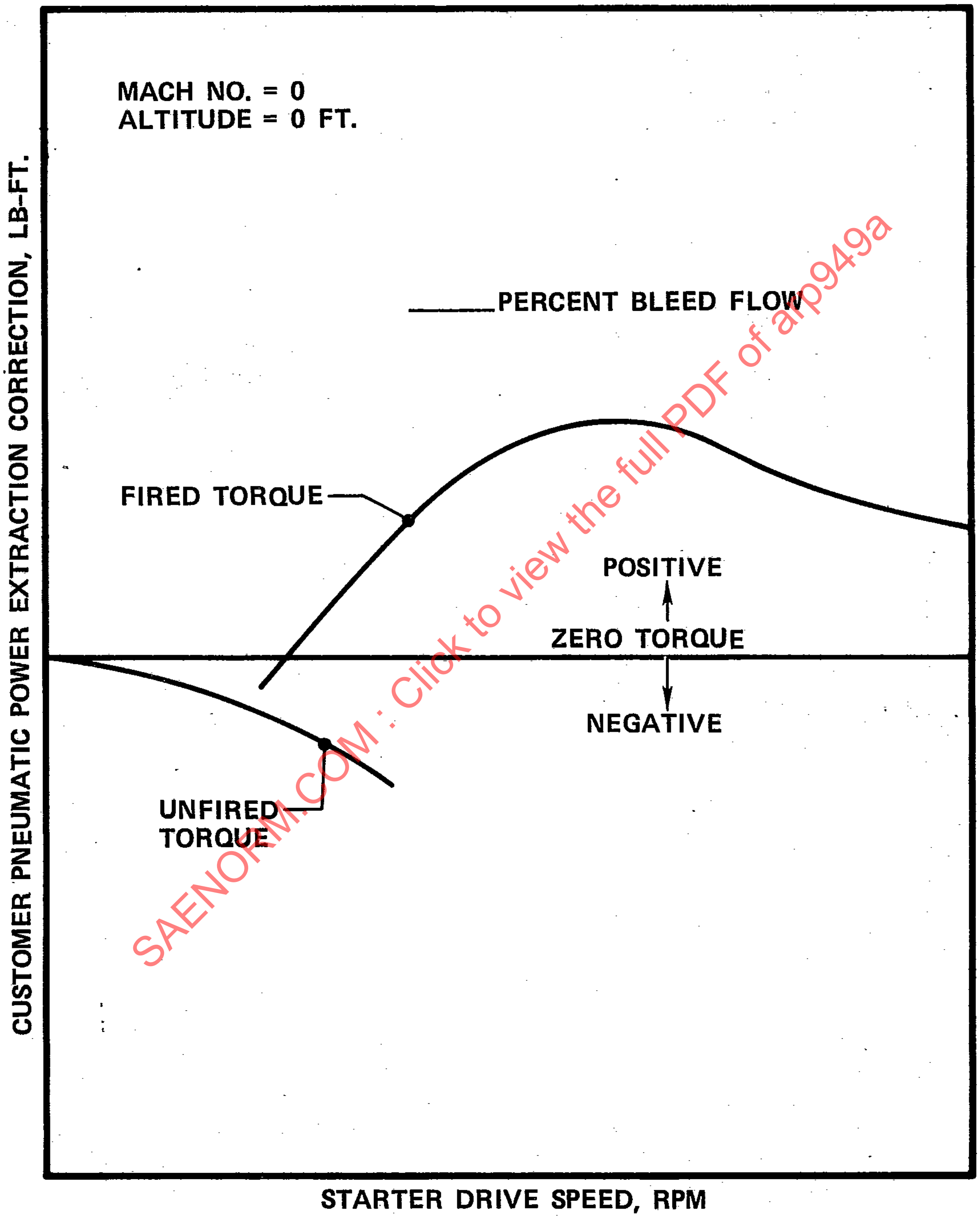

FIGURE 3

EFFECT OF CUSTOMER PNEUMATIC POWER EXTRACTION
ON ENGINE TORQUE CHARACTERISTICS

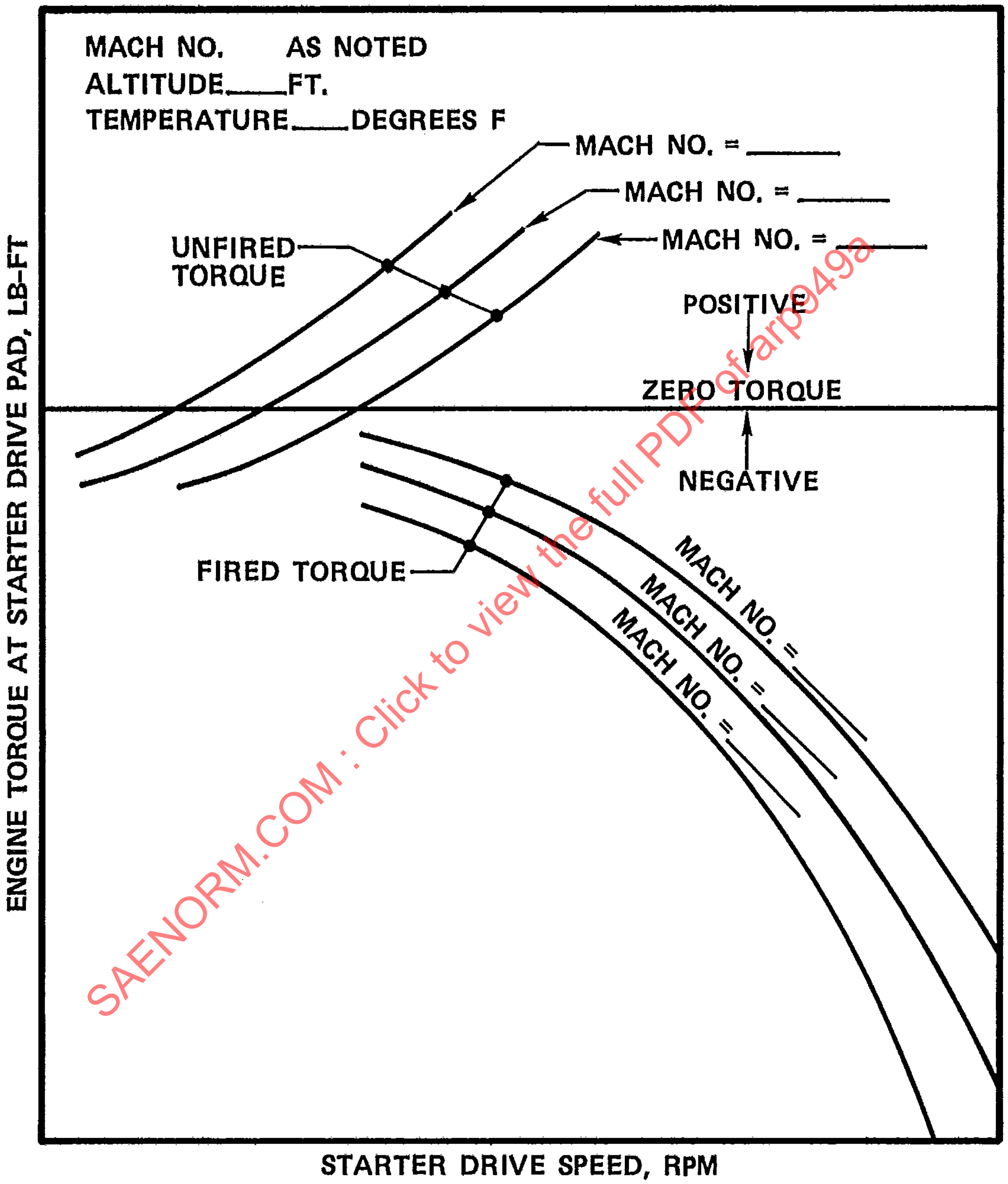

FIGURE 4

EFFECT OF FLIGHT SPEED ON ENGINE TORQUE CHARACTERISTICS

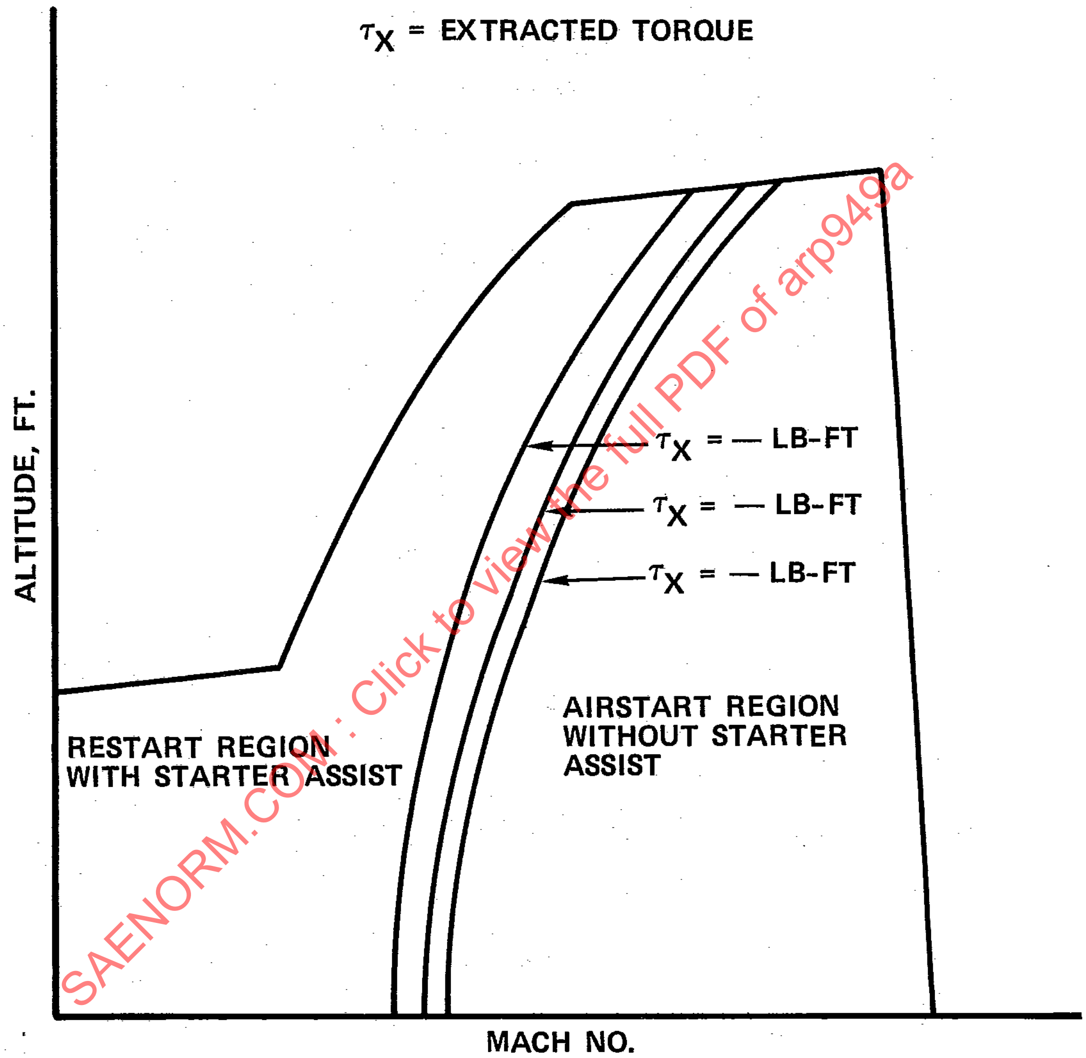

FIGURE 5

ENGINE RELIGHT ENVELOPE