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HELICOPTER POWER ASSURANCE

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1. PURPOSE:

This AIR discusses helicopter turboshaft engine power assurance theory and methods. Several inflight power assurance example procedures are presented. These procedures vary from a very simple method used on some normal category civil helicopters, to the more complex methods involving trend monitoring and rolling average techniques. The latter method can be used by small operators but is generally better suited to the larger operator with computerized maintenance record capability.

2. POWER ASSURANCE OBJECTIVES:

2.1 Turbine engine power producing capabilities can be expected to decrease with time from the new production or overhauled zero-time engine condition. The primary objective of the power assurance check is to assure that the engine remains capable of developing the power necessary to achieve the helicopter performance contained in the flight manual.

2.2 A second objective is to assure that the engine power parameter relationships required to assure continued engine airworthiness are maintained.

2.3 Substantial maintenance cost savings and safety benefits can be realized if the data obtained is recorded and monitored to detect power deterioration trends. Engine power may be checked prior to takeoff (pretakeoff power assurance) or during helicopter cruise conditions (inflight power assurance).

3. REGULATORY BACKGROUND:

3.1 The Federal Aviation Administration (FAA) has required an applicant for a commercial helicopter type certificate to provide a means to permit the pilot to determine, prior to takeoff, that each turbine engine is capable of developing the power necessary to achieve the performance required by the type certification regulations. This longstanding FAA policy was formalized as a regulatory change to Part 27, Normal Category Rotorcraft, and Part 29, Transport Category Rotorcraft, by amendments effective November 6, 1984.

3.2 This requirement to provide a means to assure adequate power prior to takeoff has generally been met by providing a pretakeoff power assurance chart. The pretakeoff check is usually performed in an in-ground-effect (IGE) hover or light-on-the-wheels. An inflight power assurance chart is often provided but is not required for type certification.

3.3 It should be noted that FAA type certification rules and policy do not require that a pretakeoff power check be performed, only that a means be made available to the pilot. Individual operational practices will dictate the frequency of the pretakeoff power assurance check.

3.4 Although this regulatory background discussion cites FAA regulations, the general principles contained in this AIR may be applied to rotorcraft certificated by other authorities using other airworthiness requirements.

4. INFLIGHT-TO-PRETAKEOFF POWER ASSURANCE COMPARISON:

4.1 Ideally, a pretakeoff and inflight power assurance check will yield the same results. Varied operating conditions and possible induction system malfunctions, however, can cause a different power margin value to be obtained from the two types of checks. The decision to use either the pretakeoff or inflight procedure, or both, depends on the operations and the intended use of the information.

4.2 Merits of Pretakeoff Power Assurance:

4.2.1 As mentioned, the FAA has insisted on the availability of the pretakeoff power assurance information or other means to allow the operator to assure adequate power for rotorcraft flight manual (RFM) performance prior to commitment to the takeoff flight phase. If the check is performed in gusty wind conditions, or with adverse winds which cause exhaust gas recirculation to the inlet, the power check on a newly delivered healthy engine may be unsuccessful. While these results do not indicate the need for engine maintenance, they do indicate that engine power may not be adequate for a critical takeoff under these specific operating conditions.

4.2.2 Certain inlet system service difficulty problems which result in loss of power at low airspeeds but adequate power at higher airspeeds may be detected by the pretakeoff check. The most common example of this type of failure would be the misinstallation or deterioration of seals which isolate induction system air from that in adjacent hot-air compartments. At low airspeeds, the reduced pressure in the inlet system would draw air from adjacent hot compartments resulting in a higher than normal inlet air temperature rise (or perhaps even inlet air temperature stratification) and an associated engine power loss. At higher airspeeds, the inlet ram pressure effect would minimize the entrainment of hot-air from the adjacent compartment, and the resulting engine power loss effect would be small. This and other low airspeed engine power loss causes may not be detectable by inflight power assurance procedures.

4.3 Disadvantages of Pretakeoff Power Assurance:

4.3.1 One obvious disadvantage of the pretakeoff check is the time required to accomplish the procedure at often uncomfortable operating conditions. While the procedure can be used as simple "go/no go" criteria (that is, as soon as the check parameters are positive the flight may commence), the flight manual may specify a dwell time to allow for engine stabilization. After changing from the low power ground operating condition to the hover IGE or light-on-the-wheels condition, there is a finite time required for engine internal components to reach their optimal clearance and power producing capability. This stabilization time may vary from only a few seconds to 5 min depending on the engine model thermodynamics and individual engine build tolerances. While the data from these lengthy power assurance checks may yield more useful power trend information and perhaps result in fewer engine rejections, the time delay in noisy ground proximity to stabilize engine power and read the power charts is not operationally desirable.

4.3.2 In-ground-effect conditions such as rotor downwash, variable wind direction, and exhaust gas recirculation may artificially influence the day-to-day variation in the pretakeoff power assurance margin when, in fact, no real change in engine power margin has occurred. This false power margin trend can lead to erroneous conclusions about the need for engine maintenance.

4.4 Merits of Inflight Power Assurance

4.4.1 The inflight power assurance check overcomes the mentioned disadvantages of the pretakeoff check. Since the inflight check is usually made in cruise conditions, it may be performed with minimal or no delays in normal operations. More accurate engine health information may be obtained at the stabilized cruise condition without the influence of rotor downwash, variable winds, and exhaust gas recirculation associated with the pretakeoff check. Stabilization time for accurate data is reduced since the engine components have already been operating at relatively high stable temperatures just prior to the inflight check.

4.4.2 The more accurate engine health information obtained from the inflight data can be utilized in a power trend monitor program to reduce operating costs. A carefully administered program can provide an early indication of the need for engine maintenance while at the same time eliminating unnecessary engine removals caused by an inaccurate power assurance check. Early engine maintenance can reduce overall operating costs by preventing premature failure of expensive engine components.

4.5 Disadvantages of Inflight Power Assurance:

4.5.1 The disadvantages of the inflight power assurance are some of those mentioned as merits of the pretakeoff check. Positive power margins from inflight power assurance checks do not necessarily ensure that engine power is available for a critical takeoff if there are inlet system malfunctions only evident at low airspeeds.

4.5.2 Inlet system and engine installation maintenance errors, and foreign object damage (F.O.D.) which result in sudden power degradation, may not be detected until after the aircraft is committed to flight.

5. POWER ASSURANCE THEORY: The safety objectives and some potential economic benefits of the power assurance procedures have been mentioned. This section will explain, in simplified terms, some of the considerations involved in constructing the power assurance charts.

5.1 The power assurance charts are typically constructed with the aid of the engine estimated performance computer program supplied by the engine manufacturer to the aircraft original equipment manufacturer. The performance program allows the helicopter manufacturer to input the helicopter model installation information for various flight conditions. The resulting installed engine power available prediction is verified by helicopter flight testing and used to predict RFM performance and generate the power assurance charts. The families of curves on the various power assurance charts are intended to check the relationship of three engine power related parameters - gas producer speed, measured gas temperature, and power (or torque). The theory involved in assuring these relationships is explained in the following sections by considering a simplified operating line for turboshaft engine types.

5.2 Minimum Specification Engine: The new production or overhauled zero-time engine acceptance test procedure will specify that the engine produce a given set of required powers (rated powers) at not greater than a corresponding set of gas producer speeds and measured gas temperatures. A plot of these power levels versus gas producer speeds and measured gas temperatures defines the "minimum specification engine runline." A different engine runline could be generated for each ambient condition, but by the application of correction factors, a single normalized runline may be constructed which is representative over a range of ambient conditions. These corrected engine performance parameters are designated shaft horsepower corrected (SHP_C), measured gas temperature corrected (MGT_C), and gas producer speed corrected (NG_C) on the accompanying figures.

5.3 Field Limit Engine:

5.3.1 (Fig. 1) At a given gas producer speed (NG) or measured gas temperature (MGT), turbine engine power will deteriorate with service time. Some engine models will not specify a delivery power margin in the engine documents to account for this normal, expected deterioration. In this case, the MGT's and NG's associated with the rated powers in the engine performance program correspond to the limit values identified on the engine type certificate data sheet. The engine manufacturer may voluntarily or contractually deliver the engine with a power margin above the engine recognized in engine certification documents. Because the designation of any power margin for service longevity is an economic rather than safety concern, the specification of a power margin is not required by regulatory authorities. Since to these authorities the minimum acceptable power versus MGT and power versus NG relationship for new delivery engines is the same as that for engines which should be removed from service, the minimum specification engine for these models is the same as the "field limit engine."

5.3.2 (Fig. 2) To account for normal, acceptable engine power deterioration, other engine models may specify a built-in performance margin or field margin in the engine documents, which may be considered as an allowable measured gas temperature increase or gas generator speed increase from a minimum specification engine. This field limit engine may be established in the engine documents (type certificate data sheet, engine specification, installation manual, or computer predicted performance program) by stipulating that the engine rated powers will be produced at some MGT or NG below the limit values. This set of reduced MGT's and NG's may be referred to as "rated MGT's" or "rated NG's," respectively.

5.3.3 To avoid possible confusion the term "field limit engine," rather than minimum specification engine, will be used to describe an engine which will produce rated power at the limits of MGT and/or NG identified in the engine documents. Power deterioration beyond the installed field limit engine, described below, would require that engine maintenance be performed in an attempt to restore power to acceptable levels.

5.4 <u>Installed Field Limit Engine (Fig. 3)</u>:

The effect of helicopter installation losses is to require a higher MGT and NG to produce a given power. The power assurance chart represents this installed field limit engine runline. Since RFM performance is also based on this runline, a comparison of an individual engine to the power assurance chart will indicate whether RFM performance can be attained.

5.5 <u>Power Assurance Data Extrapolation</u>: Since the power assurance check is often not performed at full power, the term "partial power assurance check" is sometimes used to indicate that extrapolation of the data is being assumed in predicting that RFM performance can be achieved. A valid extrapolation of partial power assurance data should account for the runline of the "worst-case-slope" engine.

5.5.1 (Fig. 4) The engine production acceptance procedures may not address acceptable engine runline slope. The ability to achieve power at each of the engine rating points at the prevailing test cell conditions may be the only power producing capability criteria used in these acceptance procedures. In the absence of delivery controls on the slope of an engine, it has been generally assumed that the runline slope of the field limit engine is acceptable for the power assurance charts. The possibility of significant extrapolation error resulting from this assumption can be minimized on helicopters without OEI power approval by typical instructions to make the check at as high a power as practicable. When large extrapolations of power check data are involved, such as when OEI ratings are approved on the helicopter, the verification of the runline slope becomes increasingly important to the assumption that a successful partial power assurance check ensures that the powers to achieve RFM performance can be attained.

5.5.2 (Fig. 5) The worst-case-slope engine may be defined in engine delivery acceptance procedures by specifying the greatest allowable increase in MGT and NG to achieve a given increase in power. In other words, the worst-case-slope engine would exhibit the least power margin at the highest of the power ratings (typically 2.5 min OEI) and the greatest power margin at the lowest of the power ratings (typically maximum continuous). If this engine minimum allowable runline slope is less than (that is, more shallow than) the runline slope of the field limit engine, extrapolation of partial power assurance data would not assure that RFM power required can be attained (see Fig. 6). Either the RFM performance and power assurance procedure should be changed to account for a field limit engine with the revised more shallow slope, or special procedures should be implemented to check the slope of individual engines.

5.5.3 Recently, some engine and airframe manufacturers have developed a procedure to establish, and periodically verify, the runline slope of an individual installed engine. This special procedure allows the power assurance procedure to account for that individual engine's performance slope rather than taking the RFM performance penalty associated with assuming the conservative worst-case-slope engine. The concept involves checking, prior to aircraft delivery, the individual engine against the engine slope assumed in establishing the power assurance charts. The minimum margin above the assumed slope is established and identified on a cockpit placard. That margin is then applied in making routine, in-service power assurance checks against the power assurance charts provided in the RFM. Thus, an engine which may have been rejected by the power assurance curves, if worst-case-slope had been assumed, may be acceptable if that individual engine's performance slope is better than worst case.

5.5.4 Some procedures incorporate a runline slope check directly into the pretakeoff power assurance procedure by requiring a specific MGT and NG margin above the power assurance chart values at a given torque setting. If that margin is not shown at this initial torque setting, the check is performed at the next higher specified torque for which data is provided, and the MGT and NG margin must be at least equal to a specified fraction of the margin at the initial lower torque setting; otherwise, engine maintenance is required.

6. <u>SUPPLEMENTAL PROCEDURES</u>:

6.1 Independent of a valid engine runline characteristic, some engine installations will need to achieve the gas producer mechanical speed limit at altitude conditions in order to produce the predicted power available for flight manual performance. Periodic gas producer speed "topping checks" are implemented to assure this capability. These checks are usually performed at altitude in order to minimize the engine exposure to high temperatures or high torque levels, or both. The topping check should be done at selected maintenance intervals, whenever an engine or a fuel control component is changed, or whenever the operator suspects the ability to achieve topping may have been affected.

6.2 Some engines with certified OEI ratings will not allow even infrequent maintenance checks to these measured gas temperatures to validate the power assurance extrapolation. The high thermal values associated with such checks would rapidly reduce useful engine life. A combination of methods including partial power assurance, topping checks at altitude, engine production control over allowable runline slope, and runline slope monitoring during the engine life may be necessary to assure the thermal and mechanical capability of the engine to produce adequate power.

6.3 Periodic checks to ensure adequate fuel flow at high power settings and limiter settings checks, may also be needed. Methods can be devised to bypass fuel from the fuel control output back to the fuel tank to check OEI fuel flow capability. Engine parameter limiter settings which are normally at or slightly above the OEI ratings can be temporarily reduced a fixed amount in order to check their function within the normal operating range.

6.4 At the high corrected gas producer speeds (NG/ Θ) sometimes associated with OEI powers, performance characteristics of engine components can change significantly. At these high corrected speeds, a given increase in MGT may not result in the increase in power which would be expected by extrapolation of partial power assurance data. The possibility that any individual engine may experience this high corrected gas producer speed phenomenon at a power level lower than that of the theoretical engine used to predict helicopter performance must be considered in the development of power assurance and supplemental procedures.

7. INFLIGHT POWER ASSURANCE METHODS:

7.1 General:

7.1.1 Three separate procedures are presented illustrating various levels of complexity for inflight power assurance procedures. Regardless of the complexity involved, all of the procedures have some common elements.

7.1.1.1 A level flight airspeed, or airspeed range where installation losses are well known, is specified. The airspeed selected should be in the economical cruise range to minimize any interruption to normal operations. The airspeed should also be such that influences of either minor variances from the target airspeed or moderately gusty winds are negligible.

7.1.1.2 Specific instructions are provided to activate or deactivate systems which can influence engine performance. These systems typically include those which extract power directly from the engine or those which influence engine efficiency. They may include bleed air systems (anti-ice, environmental control units), mechanical power extraction from the gas producer gear train (electrical generators, accessories), and possibly mechanical power extraction from the power producer gear train.

7.1.1.3 The proper positioning of controls and switches which may influence engine airflow entry conditions are specified. The activation of engine induction system (airframe supplied) ice protection systems which utilize heating would be expected to result in an engine inlet airflow temperature increase which may not have been considered in the construction of the power assurance chart. Some installations use crew controllable inlet variable geometry to provide either maximum power or maximum particle separation. The position of these devices can influence the pressure drop from ambient to the engine/airframe interface.

7.1.2 The power assurance charts should exclude low power areas where variable geometry devices (bleed valves, bleed bands, inlet guide vanes, etc.) are used for compressor surge avoidance and acceleration control. Engine efficiency suffers when these devices operate, and an accurate prediction of power producing capability cannot be made.

7.1.3 Caution should be used in specifying what systems are to be deactivated in order to assure that failure of a system during the time required for the check does not jeopardize continued safe operation.

7.2 Example 1 (Appendix A):

7.2.1 Example 1 is a procedure used on a normal category civil rotorcraft without OEI ratings such that the extrapolation of the partial power assurance data to the highest torque rating available, or to the aircraft torque limit, is not extensive. The runline slope of the specification engine is assumed to be worst case.

7.2.2 The procedure does not check the NG versus torque relationship. In this installation, this particular engine model will be rejected by the MGT versus torque check before it is incapable of producing RFM power required at the limit gas producer speed.

7.2.3 This inflight power assurance procedure is a simple one-point pass or fail check with no trending procedure involved.

7.3 Example 2 (Appendix B): Example 2 is used on a transport category civil rotorcraft with performance credit for OEI power ratings. The procedure first checks the gas producer speed versus torque relation, then verifies the proper NG versus MGT characteristic.

7.4 Example 3 (Appendix C):

7.4.1 The power assurance procedure for example 3 is more complicated than most others, but it does offer more precise information on engine health and should provide an early indication of the need to schedule engine maintenance. The procedure consists of two major parts, the acquisition of inflight power information and the postflight data reduction of that information.

7.4.2 The inflight data acquisition can be subdivided into two elements, the periodic "Power Assurance" check at 30 min OEI Rated Power and the "Daily Trend" checks in cruise near Normal Cruise Rated Power.

7.4.2.1 Initial Power Assurance check information is gathered at 30 min OEI power at a specified airspeed associated with minimum power required for level flight in order to determine the initial power margin. This is followed by repeated data acquisition at this power level every 50 engine flight hours, as required by engine maintenance or deterioration, or at the option of the pilot.

7.4.2.2 Daily Trend check information is obtained at Normal Cruise Power at a specified airspeed at a nominal specified altitude. If possible, all power assurance information should be obtained at the same pressure altitude in order to eliminate altitude variations in the flight data.

7.4.3 Processing of the flight data is done after shutdown, but prior to the next flight. Composite graphs of minimum acceptable torque at various MGT's and ambient conditions are provided. The data is charted and monitored for power trending.

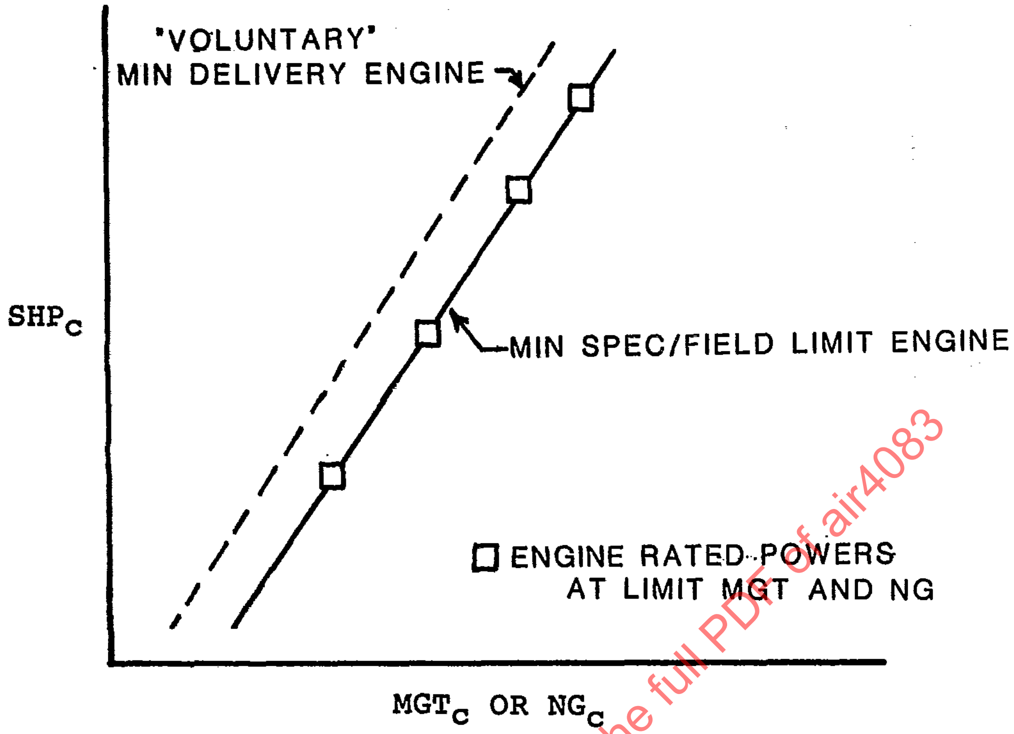

FIGURE 1

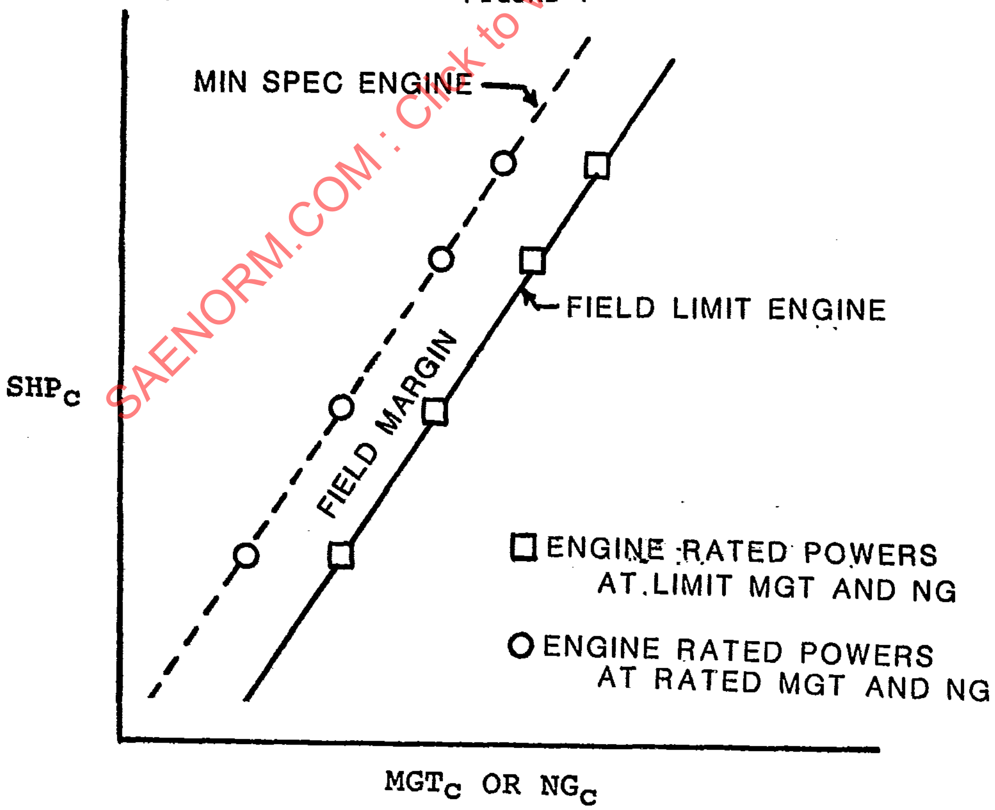

FIGURE 2

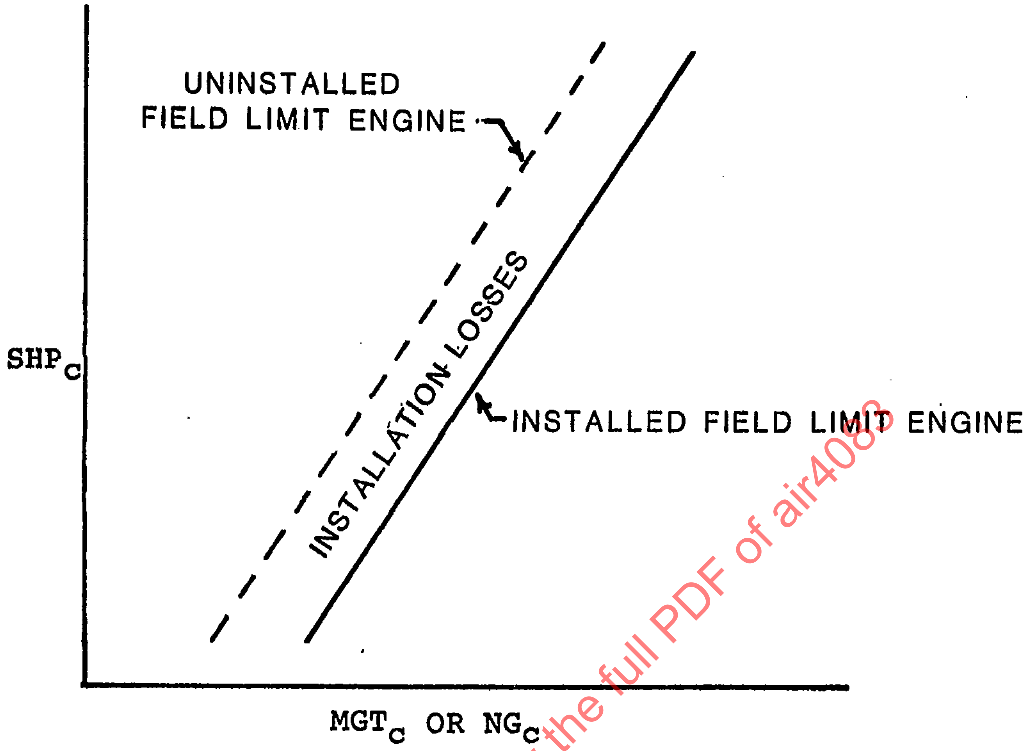

FIGURE 3

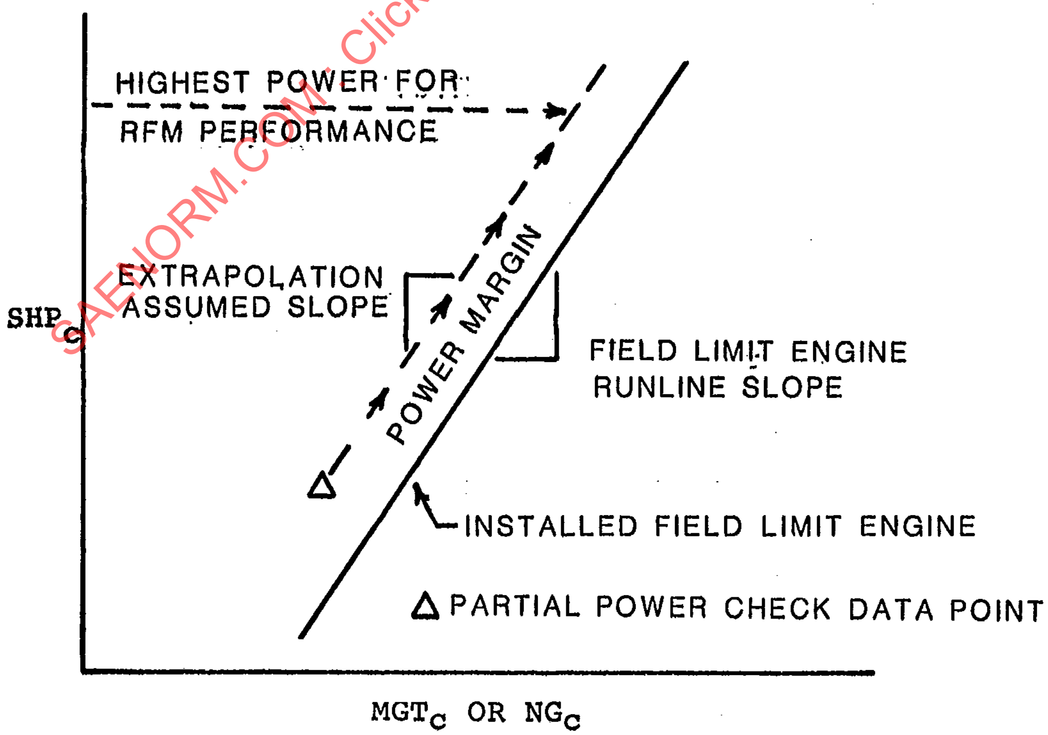

FIGURE 4

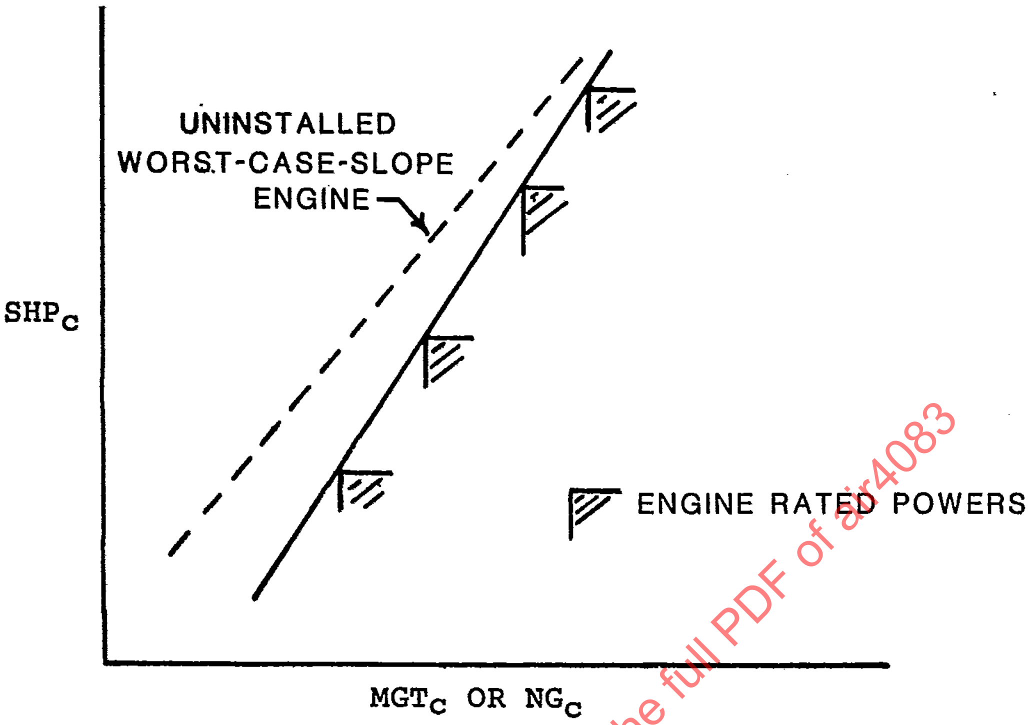

FIGURE 5

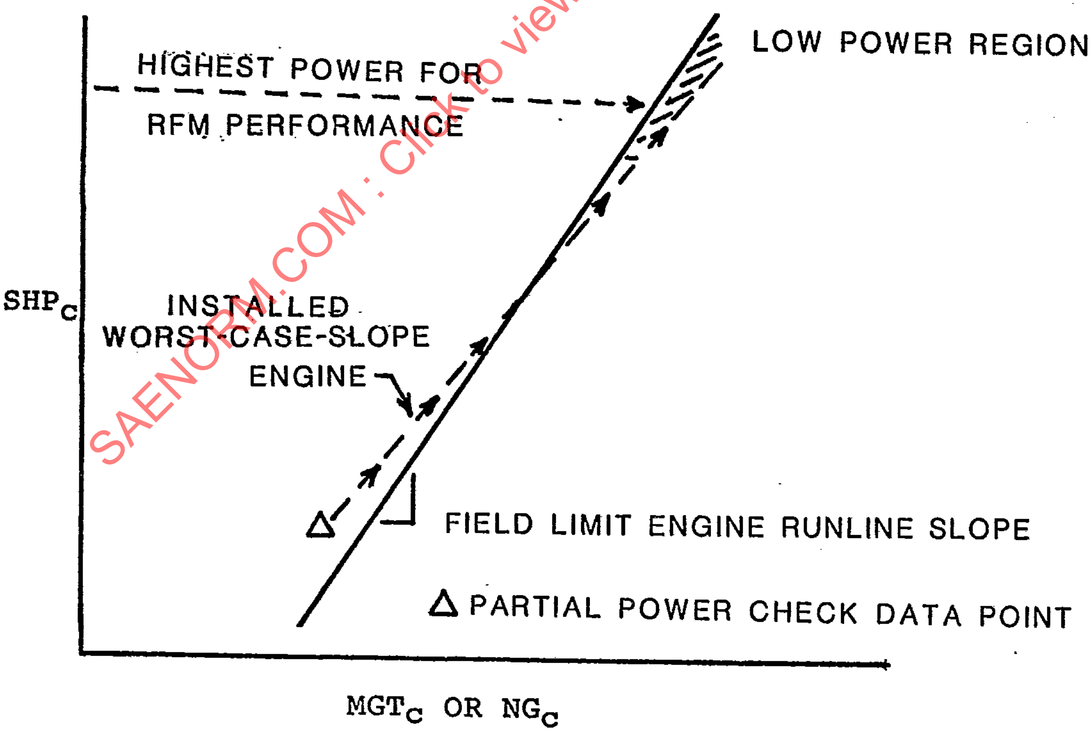

FIGURE 6

APPENDIX A

EXAMPLE 1 PROCEDURE (FIG. A1)

A.1 Turnoff all sources of bleed air, including engine anti-ice.

A.2 Establish level flight at a specific airspeed range, not to exceed V_{NE}.

NOTE: The loading condition of the DC generator, driven by the engine's gas producer gear train, is not specified in the text. The load identified on the chart, however, represents nominal generator loading for cruise conditions.

A.3 Record pressure altitude, outside air temperature (OAT), measured gas temperature, and percent torque from the cockpit instruments.

A.4 Enter the chart at the observed OAT, proceed vertically to intersect the indicated MGT, follow horizontally to intersect pressure altitude, and then drop vertically to read the minimum torque which should be available.

A.5 If the torque indication from the cockpit instrument is greater than or equal to the torque read from the chart, the engine equals or exceeds minimum performance specification, and RFM performance can be achieved.

A.6 If the cockpit indicated torque is less than the required chart torque, engine power is less than minimum specification, and the performance in the RFM cannot be achieved.

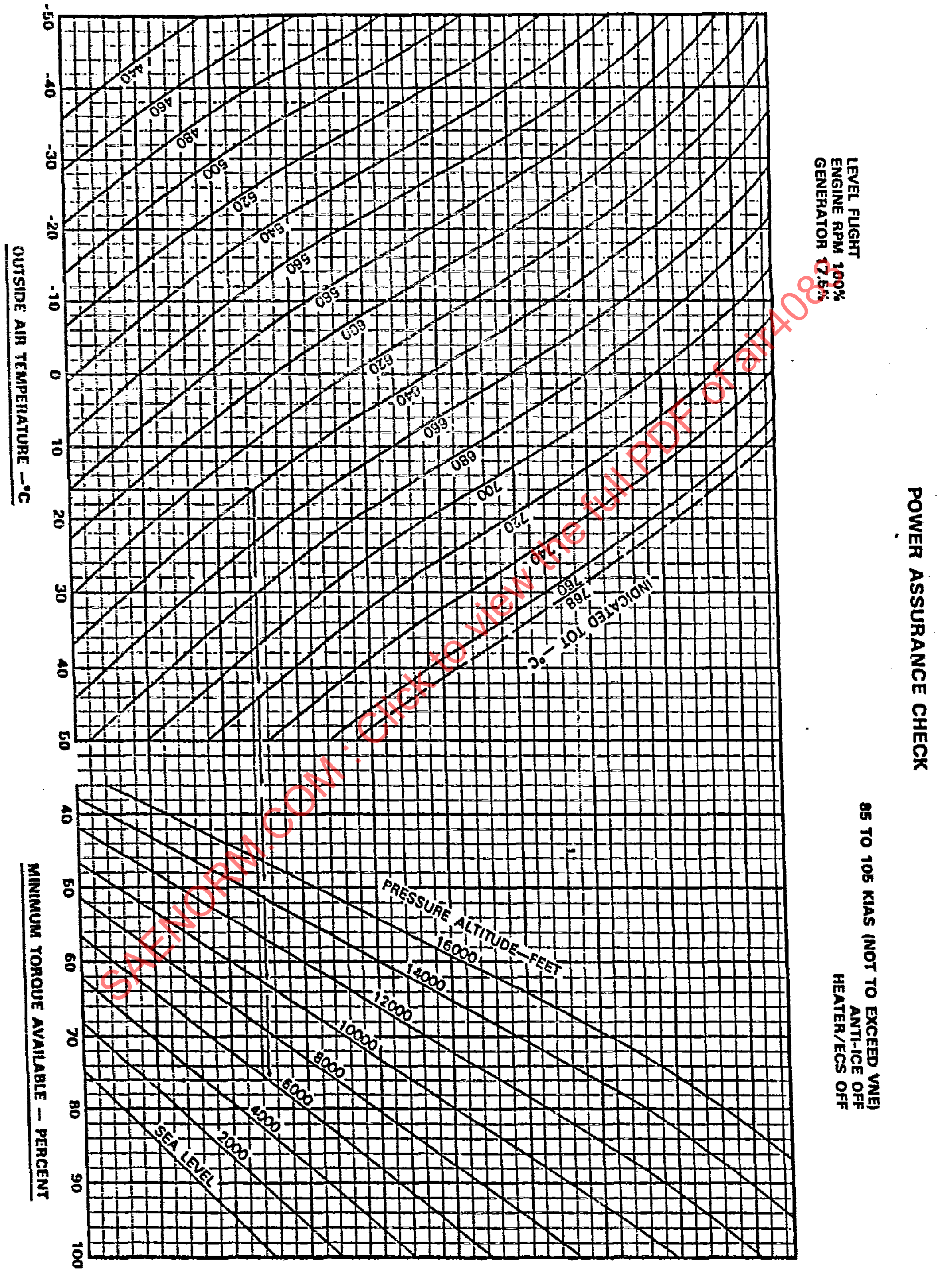
POWER ASSURANCE CHECK
LEVEL FLIGHT
ENGINE RPM 100%
GENERATOR 17.5%
85 TO 105 KIAS (NOT TO EXCEED VNE)
ANTI-ICE OFF
HEATER/ECS OFF
INDICATED TOT — °C
440
460
480
500
520
540
560
580
600
620
640
660
680
700
720
740
760
768
OUTSIDE AIR TEMPERATURE —°C
-50
-40
-30
-20
-10
0
10
20
30
40
50
PRESSURE ALTITUDE—FEET
16000
14000
12000
10000
8000
6000
4000
2000
SEA LEVEL
MINIMUM TORQUE AVAILABLE — PERCENT
40
50
60
70
80
90
100

FIGURE A1

APPENDIX B

EXAMPLE 2 PROCEDURE (FIGS. B1 AND B2)

B.1 Perform the NG versus torque check (Fig. B1) as follows:

B.1.1 Place the aircraft in stabilized multiengine level flight for at least 3 min at economical cruising speed at a precise, specified collective pitch setting. Switchoff any customer bleed air devices.

B.1.2 Record torque, MGT, and gas generator speed for each engine, and rotor speed, pressure altitude, and outside air temperature.

B.1.3 For each engine, at the indicated NG (1) move horizontally to the left using Fig. B1 to intersect the recorded OAT (2), then move vertically to intersect the pressure altitude (3). Project a line horizontally from the pressure altitude intersection (3) into the upper right-hand quadrant of the chart.

B.1.4 From the indicated torque value (4) for each engine in turn, move horizontally to intersect the relevant NR curve (5). Project a line vertically from the NR curve intersection (5) into the upper right-hand quadrant of the chart.

B.1.5 Determine the intersection point (6) of the lines coming from the pressure altitude point (3) and from the NR point (5).

B.1.6 If the final intersection point (6) falls within the shaded region, RFM performance may not be achieved, and maintenance should be performed.

B.1.7 If the final intersection point (6) falls within the unshaded region, adequate power will be produced for RFM performance if the "thermal load check," which follows, is satisfactory.

B.2 The NG versus MGT, thermal check load (Fig. B2) is performed using the preliminary information obtained for the preceding NG versus torque check.

B.2.1 From the recorded NG (1) move horizontally to the right to intersect the measured OAT curve (2).

B.2.2 Project a line vertically downward from the OAT curve (2) into the lower half of the chart.

B.2.3 From the recorded MGT (3), project a line horizontally to the right to the intersection (4) of the vertical line from the OAT curve (2).

B.2.4 IF the intersection point (4) is in the unshaded region of Fig. B2, adequate power will be produced for RFM performance if the NG versus torque check was likewise successful.

B.2.5 If the intersection point (4) falls in the shaded region, RFM performance may not be achieved and maintenance should be performed.

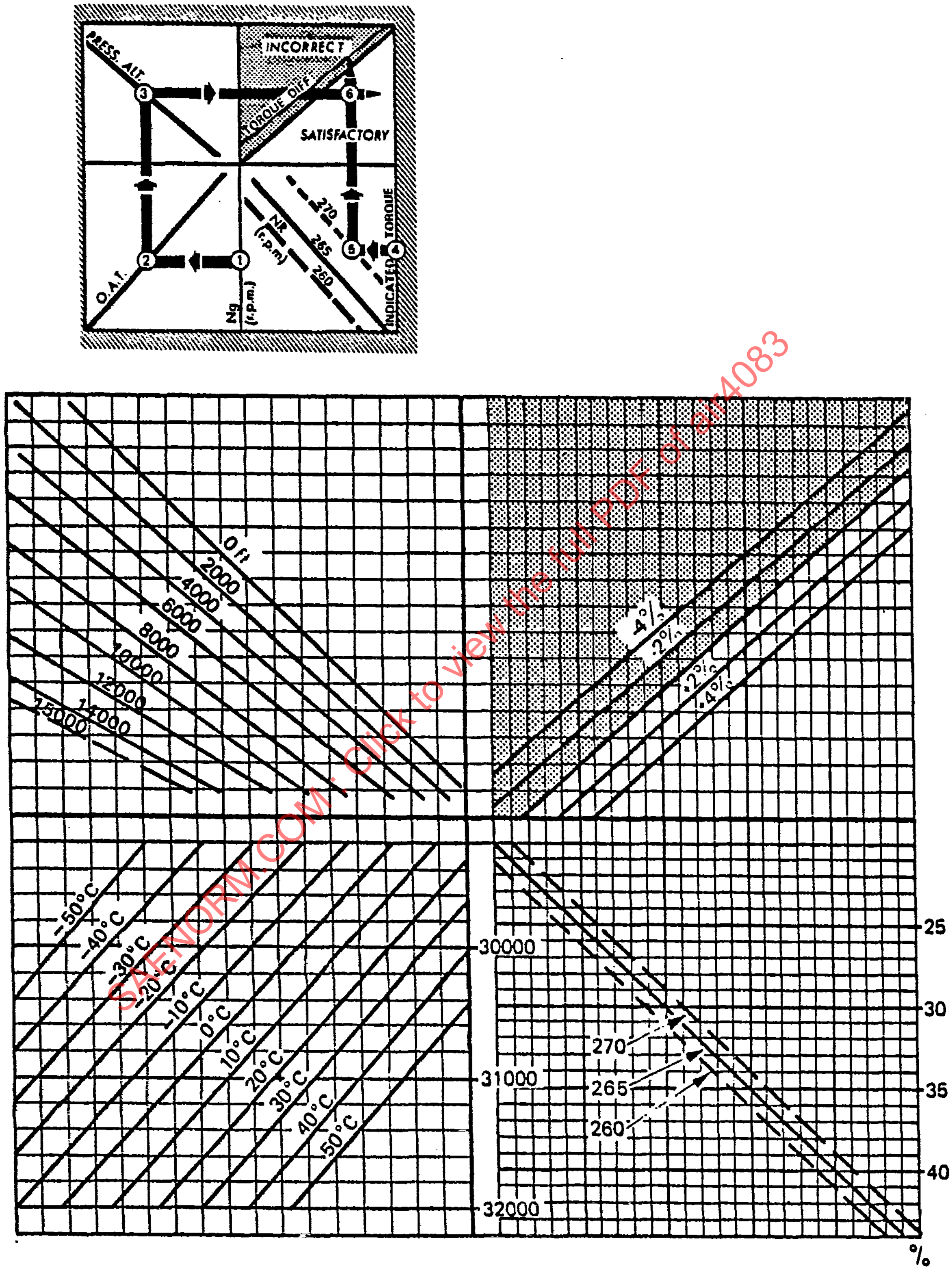

FIGURE B1 - In-Flight Engine Power Check

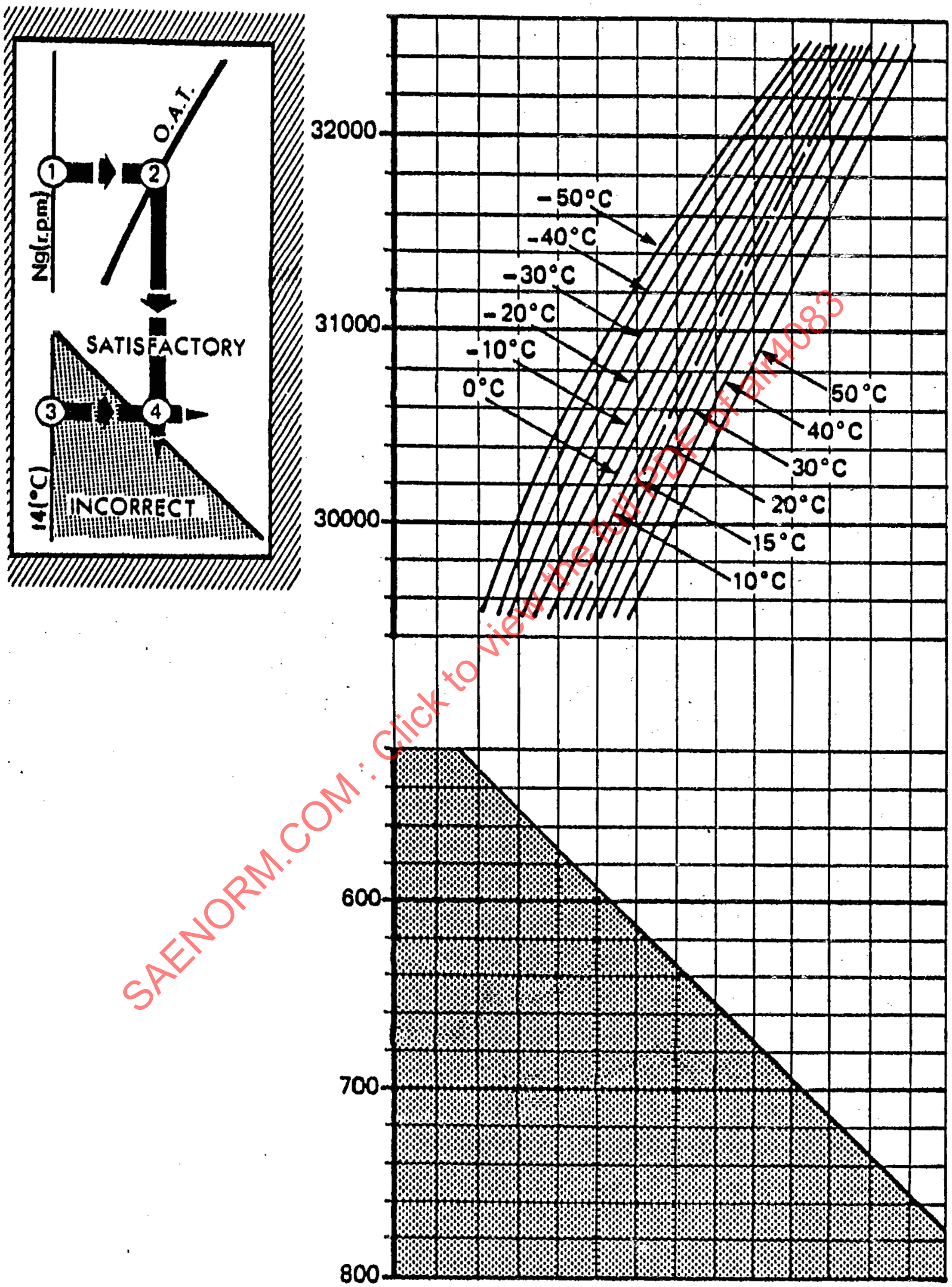

FIGURE B2 - Engine Thermal Load Check