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A SERVICE PUBLICATION OF LOCKHEED-GEORGIA COMPANY, A DIVISION OF LOCKHEED CORPORATION

CONSERVING TURBINE LIFE

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A SERVICE PUBLICATION OF
LOCKHEED-GEORGIA COMPANY
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LOCKHEED CORPORATION

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Cover: During the last quarter of 1986, the U.S. Marine Corps added two rather special Hercules aircraft to their KC.130 fleet. The advanced model KC-130T tanker/transports are the 1799th (front cover) and 1800th Hercules airlifters to be rolled out of Lockheed's production line. The Marine Corps KC-1305 have now accumulated the equivalent of more than 70 years of accident-free flying.

Cover photographs by John Rossino Engine component photographs on pages 4 through 13 courtesy of Allison Gas Turbine Division, General Motors Corporation.

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Focal Point

GLENN M. GRAY

The Difference That Counts

[redacted]

cules operator is the fact that of the more than 1800 that have been built, nearly 86 percent are still in operation.

Statistics like these say a lot about an airplane, about the way it isdesigned and built, and aboutthefundamental role that quality has played in every phase of its manufacture.

We at Lockheed take pride in this record, but we know that the numbers also have another story to tell, That is a story about people, the people who fly the airplanes of the worldwide Hercules fleet, and the people who maintain them.

Flight crew and maintenance technicians are at the forefront of the effort to maximize the service life of an airplane. It is they who translate inherent, latent qualities such as good design, mechanical ruggedness, and modern safety features into the real "bottom line" in the world of aviation: performance and service life.

How do they do it? On the operational side, my area of specialization, it comes down to making a habit of sound and conservative operational practices. Among otherthings, this means reducing wear and tear on brakes and tires by using reverse thrust for slowing the airplane whenever conditions permit; setting flaps at 50% during engine run-ups to best distribute stresses between flaps and empennage; using low-speed ground idle for taxiing as much as possible; extending engine life by limiting exposure to high TIT; and followingthe recommendations contained in this issue of Service News.

In short, it is done through professionalism, dedication, and the everyday application of good sense. It is never by coincidence or happenstance that a product of modern technology such as the Hercules airlifter becomes preeminent in its field. We are proud of the quality we build into our products, but we are prouder still of the tradition of intelligent teamwork that has brought the Hercules family so much of its success. It's the difference that really counts.

Sincerely,

Glenn M Gray

Glenn M. Gray
Director of Flying Operations

PRODUCT SUPPORT LOCKHEED-GEORGIA COMPANY
MARIETTA, GEORGIA 30063

M. M. HODNETT DIRECTOR

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CONSERVING TURBINE LIFE

The single most important cause of degraded performance and premature failure in gas turbine engines is exposure to excessive heat.

It makes little difference from the standpoint of the effect on the engine what the cause of the overtemperature condition might be. What is important is only the degree of the overheating and how long it continues.

Each and every exposure to excessive operating temperatures takes its toll on engine life, decreasing operational efficiency and increasing maintenance costs.

The important role that is played by the practices of individual Hercules aircraft operators and their maintenance organizations in determining engine service life is not always fully appreciated.

The fuel system of the Allison 501/T56 engine that powers the Hercules aircraft is provided with effective, automatic controls that keep engine temperatures within safe limits over a wide variety of operating conditions.

As good as this system is, however, it was not designed to work alone. It cannot take the place of careful and conscientious management of the overall operational environment. This is something only the human side of the equation can provide.

Life Cycle Factors

The normal maximum time between overhauls for a particular model of the Allison 501/T56 engine is established on the basis of engineering considerations, user experience, and a careful evaluation of any safety factors involved.

Within that time period, however, an engine's individual maintenance requirements are largely determined by the effects of the operating environment upon major engine components.

For example, in areas subject to blowing sand or heavy burdens of dust in the atmosphere, the compressor section may be seriously eroded long before other parts

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of the engine require attention. More typically, the repair intervals will be determined by the condition of the turbine, combustion liners, and inlet guide vanes of the "hot" section.

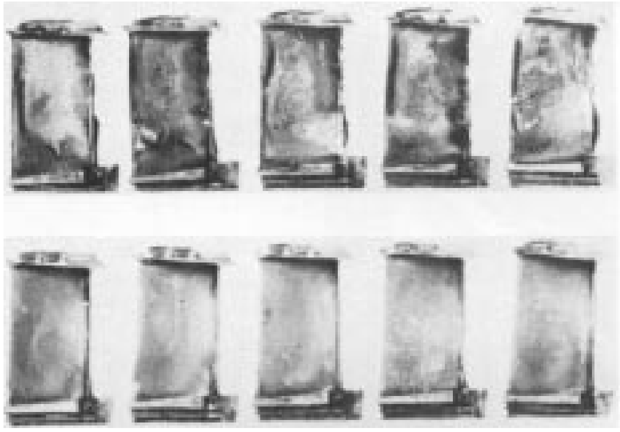
The turbine section components are made of metal alloys designed to be as durable as possible in a high-temperature operating environment. Their service life is nevertheless rather dramatically affected by the temperatures to which they are subjected. Metals do not "forget" incidents of exposure to overtemperature conditions. Repeated exposure to high temperatures will eventually result in changes in their physical characteristics that can lead to material failure.

Let us look at some of the effects of high-temperature engine operation on turbine vanes and blades in a little more detail.

Sulfidation

Turbine blades and vanes are subject to gradual deterioration as engine operating hours accumulate. This process is commonly referred to as sulfidation. Turbine sulfidation is caused by the accelerated oxidation of metals in the presence of sulfur ions, in particular sulfides and sulfates. The oxidized metal goes out the tailpipe, leaving eroded blade and vane surfaces behind.

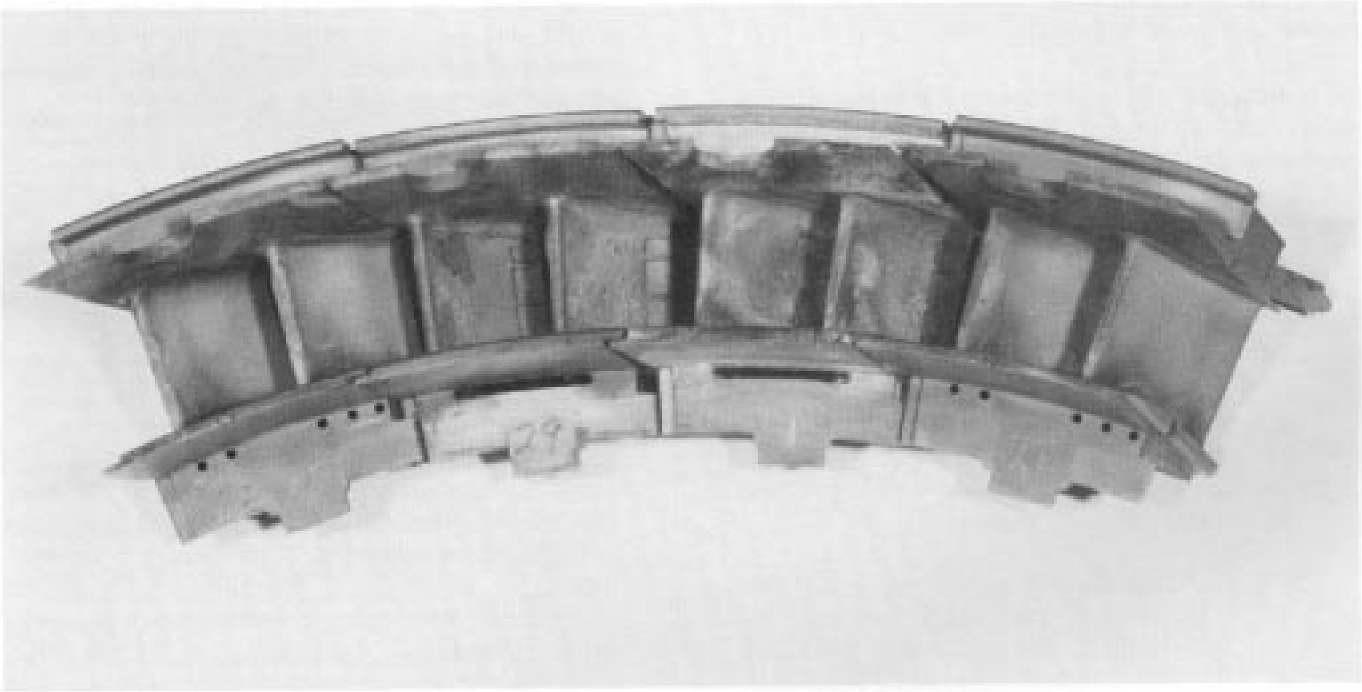
To help prevent such damage to the metal surfaces and extend the service life of the turbine section components most often affected by sulfidation, diffused coatings of aluminum or aluminum and chromium (often referred to as Alpak and AEP, respectively) are applied to new turbine blade and vane surfaces.



First stage turbine blades after service test.
Top row: uncoated alloy.
Bottom row: the same alloy protected with Alpak.

These coatings are effective while in place, but they are eventually eroded away by the hot gases and abrasive particles passing through the turbine section. This means that sooner or later the base metal of turbine components will become exposed to the damaging effects of sulfur ions.

First stage turbine vane sulfidation.



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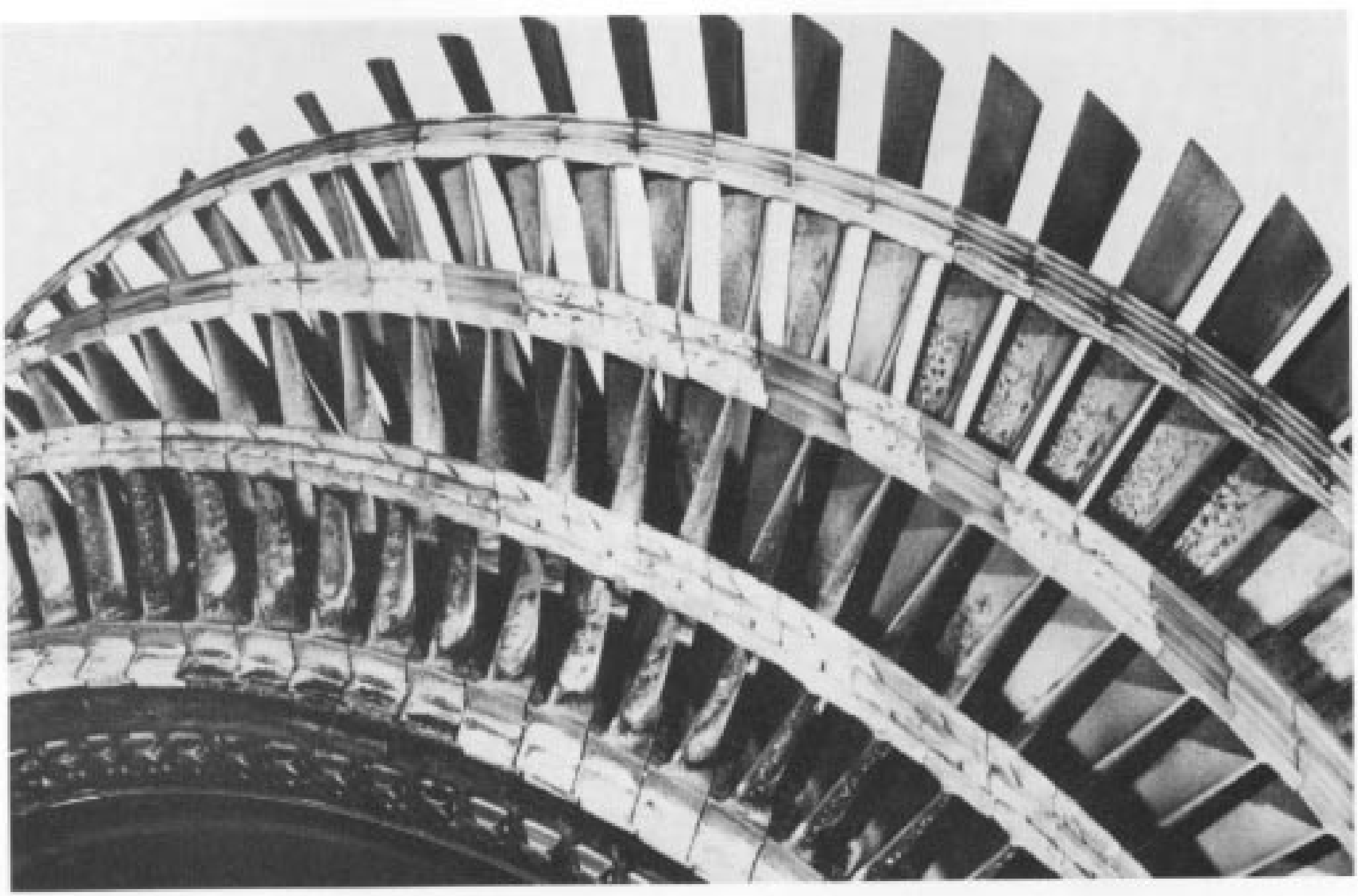
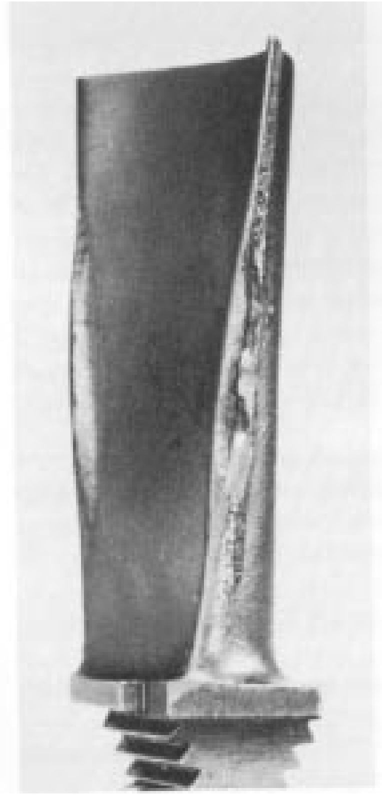


Air-cooled turbine rotor after accelerated sulfidation testing.



Close-up of turbine blade sulfidation damage.

Controlling Sulfidation

The sulfur ions responsible for sulfidation come from a variety of sources and are not entirely avoidable. They may come from the sulfates in sea water, sulfur in jet fuel, the sodium sulfate in aircraft cleaning solutions, hydrogen sulfide and sulfur dioxide in the air, or sulfur-bearing particulates injected into the atmosphere by industrial processes.

While sulfidation is by far the most common and most pervasive of the destructive processes affecting turbine components, it is also in some ways the most controllable. The key to reducing the damaging effects of sulfidation lies in understanding the factors involved in the process.

The rate at which sulfidation occurs in the engines is dependent on three factors:

1. Hours of operation.
2. Concentration of sulfur ions.
3. Temperature of the metal components.

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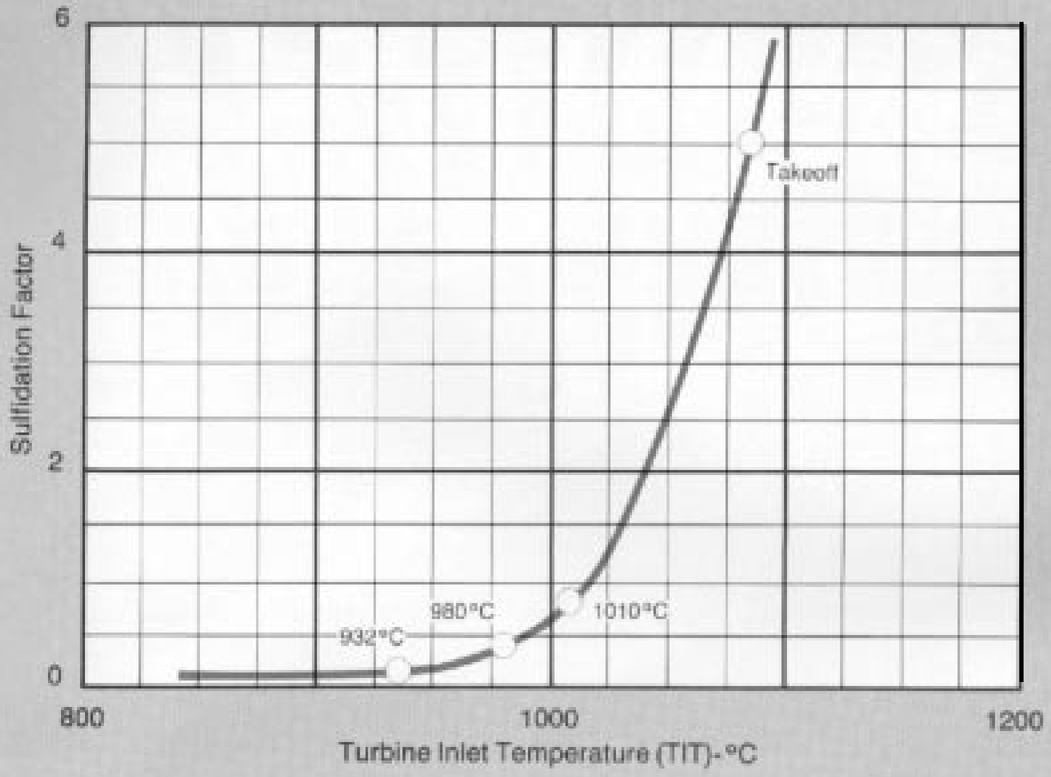

Effect of Temperature on Sulfidation.

There are limits to what can be done about some of these influences. It is obviously impractical to reduce the operating hours of an airplane just to avoid the sulfidation problem. It is also impossible to avoid encountering the sulfur ions in the atmosphere totally, although it is wise to avoid areas of heavy industrial pollution and unnecessary low-altitude exposure to sea air.

For all practical purposes, the first two of these factors can be regarded as constants, more or less beyond the operator's control. The situation is quite different, however, in the case of the third factor.

How rapidly protective coatings like Alpak and AEP are worn away, and how rapidly sulfidation proceeds thereafter, is strongly affected by the operating temperature. Sulfidation is fundamentally a chemical reaction and, like most chemical reactions, it proceeds more rapidly at higher temperatures. It is no coincidence that this destructive process is often called simply "hot corrosion. "

Sulfidation rates tend to be exponentially related to the temperature of the metal, as **shown** in the chart above. It is important to remember, however, that turbine temperature is not a constant. The temperature at which the turbine of the 501/T56 engine operates is a variable which is largely within the control of the operator.

Reducing Sulfidation Effects

There are three principal ways in which flight crews and maintenance specialists can help in reducing the temperatures that turbine section components are exposed to, and thereby retard the sulfidation process.

1. Fly at reduced cruise TIT whenever possible:'
2. Pay careful attention to starting temperatures.
3. Ensure that the TIT sensing and indicating system is properly maintained.

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Cruise Conservation

Consider a mission where all parameters are fixed except for cruise TIT. A reduction of only 30 or 40 degrees metal temperature will reduce the sulfidation factor by almost one-half. Even further increases in turbine life may be realized with further reductions in cruise TIT. When operation of the aircraft can be accomplished with a lower TIT, the life of the turbine section is greatly increased.

Furthermore, the sacrifice in terms of airspeed that will result from a modest reduction in TIT is really quite small.

The charts on pages 8 and 9 provide a comparison of power settings and their effect on cruise time or fuel consumption over a given distance. These charts help point up the relatively minor time advantage that can be expected from exposing the turbine sections of an aircraft's engines to high cruise TIT.

For 501-D22A, T56-A-15, T56-A-16, and T56-A-423 engines, decreasing power from 1010 degrees C to 971 degrees C increases block time only about 3.8 minutes per hour of block time, while a further reduction to 932 degrees C increases block time by just 6 minutes per hour.

Furthermore, it is possible to achieve fuel savings of approximately 3 percent with a TIT reduction from 1010 degrees C to 971 degrees C. A total of approximately 5 percent savings may be realized by reducing engine power from 1010 degrees C to 932 degrees C.

This points up two of the reasons why Lockheed recommends that climbout TIT for this series of engines be set no higher than 971 degrees whenever possible, and cruise temperatures be set no higher than 932 degrees C whenever possible. Relatively little extra speed is to be gained from the use of high TIT settings, and these same settings are also wasteful of fuel.

But most important, lower power settings will contribute greatly to a longer turbine life.

The same conservation philosophy can also be applied to 501-D22, T56-A-9, and T56-A-7 engines with good effect, although in these cases the temperature settings will be lower. A number of operators of Hercules aircraft equipped with these engines have found that keeping continuous cruise TIT at 900 degrees C or below yields excellent results.

The nature of aircraft operations requires that aircraft engines be subjected to high power outputs and high temperatures on many occasions during their time in service. However, experienced operators have discovered that conservative engine temperature settings in cruise and at other times when safety and operational considerations allow it will yield worthwhile benefits in terms of turbine section reliability and reduced operating costs.

Stress Rupture

Another heat-related factor which must be taken into consideration in realizing maximum engine service life is stress rupture. Stress rupture is breakage of turbine blades as a result of exposure to physical stress. This characteristic is time-dependent and a result of the stresses applied by centrifugal force (turbine rpm) and temperature in the turbine's operating environment, normally expressed as TIT.

The relationship between temperature and turbine blade "stress rupture life," a measure of resistance to breakage of this type, is shown on the chart on page 10. Note how a 30-degree C increase above the normal operating temperature will decrease the stress rupture life by two-thirds. On the other hand, a 30-degree C decrease in blade metal temperature can triple stress rupture life.

Relatively few instances of actual turbine blade breakage due to stress rupture have been recorded for the Allison 501/T56 engine, but in the majority of these cases inspection of the affected parts has revealed previous exposure to an overtemperature condition.

A Good Start on Conservation

Starting the engines is always a minor moment of truth for an aircraft mission; the start can also be something of a moment of truth as far as the engine turbines are concerned.

To obtain good starts with consistency, be sure to comply with the checklist procedures closely. Pay particular attention to the following:

- TIT is the most important gage during starting. Watch this gage continuously during start.
- The throttle must be in the GROUND IDLE (military aircraft) or GROUND START (commerical aircraft) position.

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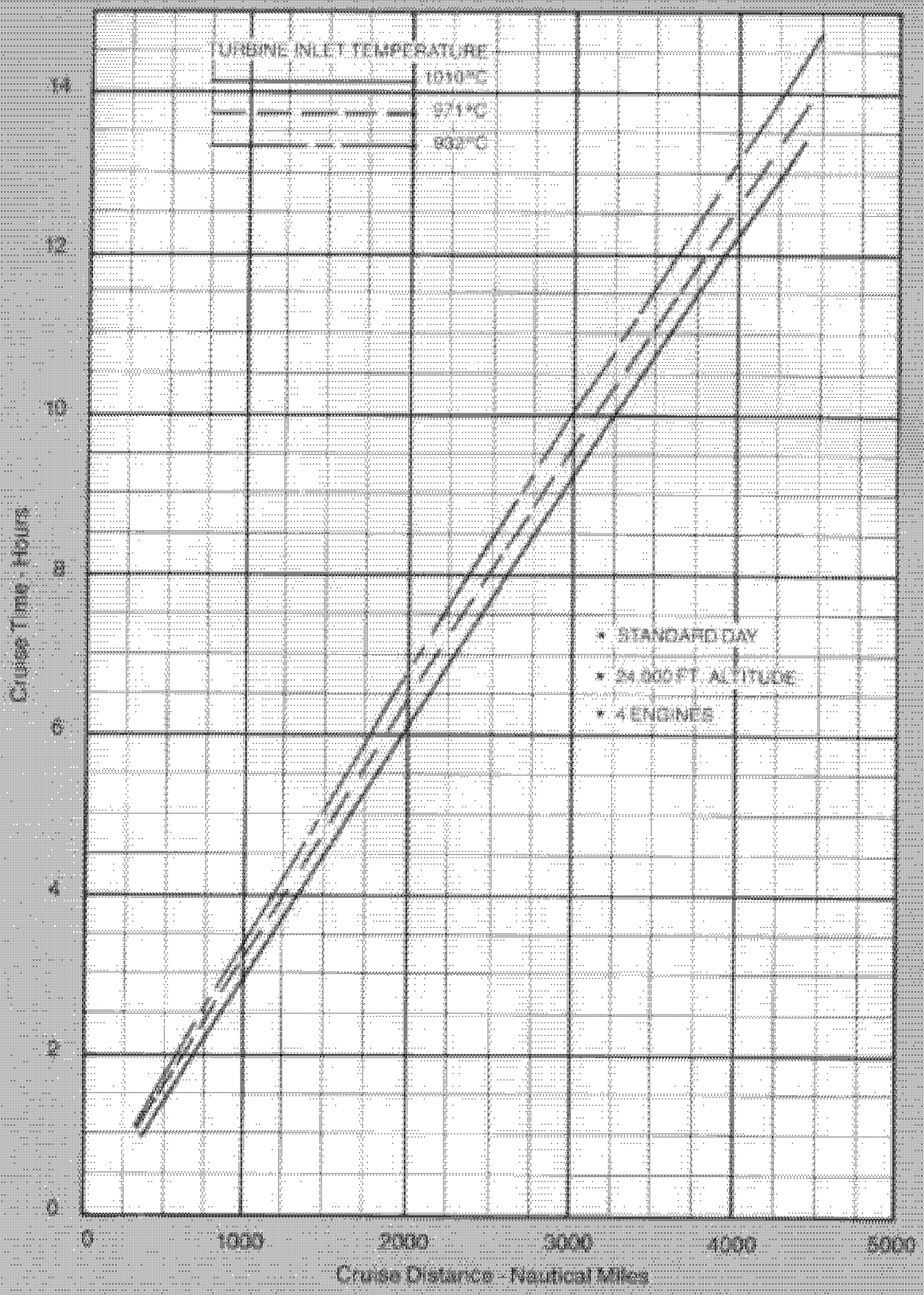

Cruise Time Versus Distance

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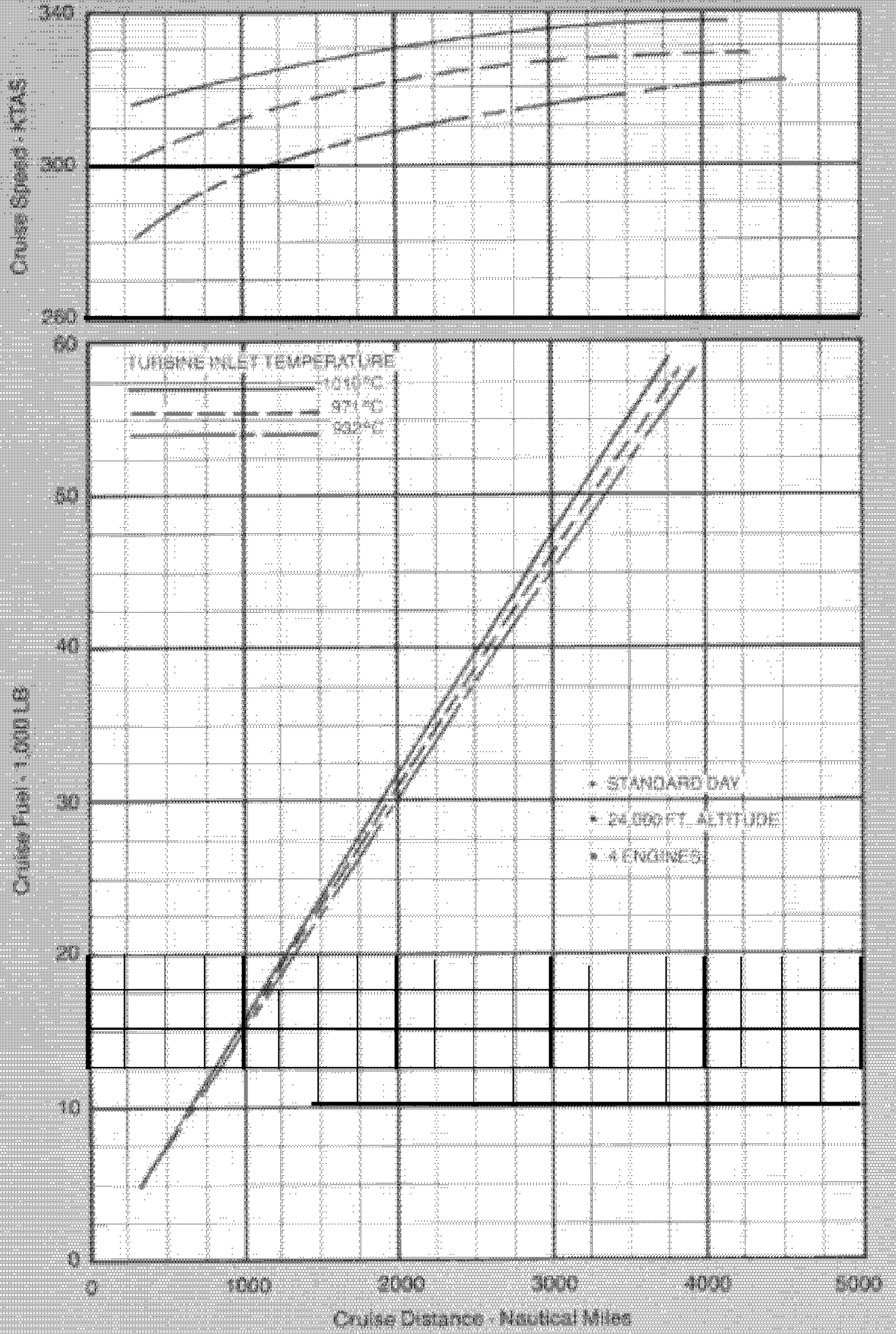

Cruise Fuel Versus Distance

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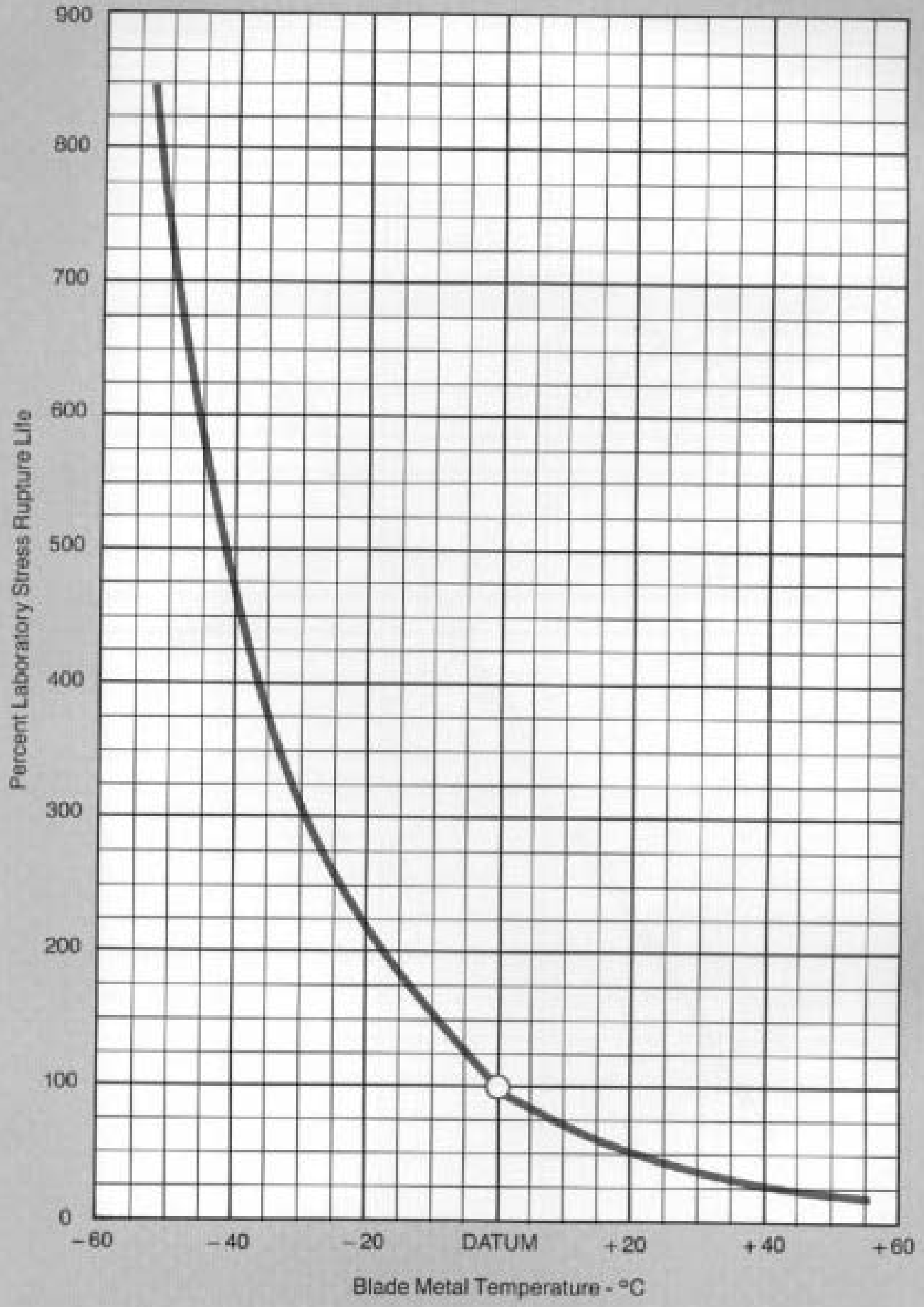

Effect of Temperature on Turbine Blade Materials

- The propeller should be at minimum torque blade angle.

- Aircraft boost pumps should be ON for the start to ensure a good fuel supply to the engine fuel systems.

- Be sure that the residual TIT in the engine is less than 200 degrees C before initiating a start.

- The GTC or APU should be operating properly and at maximum output. Always check for a minimum bleed air manifold pressure of at least 35 psi before the start is initiated, and a minimum of 22 psi during the start itself.

- Air conditioning must be off during engine start, and the ATM should be off unless absolutely needed. In cases where the ATM must be on for some reason, be sure to monitor the bleed air pressure very closely while starting the first engine.

- On manually controlled starter systems, be sure that the engine reaches 60% rpm, then release the starter switch or button promptly to ensure maximum starter life.

- Observe engine acceleration rate and the start time specified in the applicable technical manual and operator handbook.

- Do not use enrichment on normal ground starts unless the engine will not light off without it; however, all in-flight starts should be accomplished using enrichment.

- Closely monitor engine instruments throughout the start cycle.

- Check for first rpm indication, which indicates that the start cycle has begun. Lightoff ordinarily occurs between 14% and 24% rpm, and acceleration should be continuous until the engine is on speed.

- If enrichment is used, check for fuel flow and immediate cutback after 16% rpm. Disregard for the rest of the start.

- The secondary fuel pump pressure light should be steadily illuminated by the time the engine reaches 65% rpm. It should go out above 65% rpm.

While the start cycle usually occurs without difficulty, each start must be closely monitored so that it may be abandoned in case an unexpected problem arises. The start **should be aborted** for any of the following reasons:

- TIT exceeds temperature limits cited in the applicable manuals.

- Bleed air manifold pressure falls below the minimum acceptable value of 22 psi.

- Hesitating or stagnating rpm.

- Fuel is observed pouring from the nacelle drain.

- Torching-visible burning of fuel in and aft of the tailpipe-is observed. Note that a momentary burst of flame, an "enrichment burst," is normal if enrichment is selected.

- Excessive smoke is seen from the exhaust.

- Compressor surging or stalling occurs.

- Abnormal vibration is noted.

- Permissible start time is exceeded.

- The engine does not light off (no increase in TIT) by 35% or maximum engine rpm attainable with the starter, whichever occurs first.

Problem Starts

The most desirable engine start is of relatively short duration (less than 60 seconds), with peak TIT between 780 degrees C and 810 degrees C. Starting temperatures cooler than 780 degrees C are not necessarily better ones.

Temperatures on the cool side may result in acceleration rates inadequate to complete the start within the prescribed time limit. Low starting temperatures may be evidence of a lean TD null orifice valve setting or a lean fuel control acceleration schedule.

These misadjustments can produce improper fuel nozzle flow patterns and result in such problems as downstream burning of fuel, excessive blade/vane heat soak temperatures, and a high incidence of aborted starts.

On the other hand, starts with turbine inlet temperatures on the high side apply a great deal of

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thermal stress to the turbine section of the engine. The rapid expansion forced upon turbine vanes, blades, and other critical components by the sudden application of extreme heat can cause the parts to crack.

Such “hot starts” can do a lot of damage in a short period of time and must be avoided. The following are the start overtemperature limitations and the required action if exceeded.

Over 830 degrees C

TIT over 830 degrees C, but excluding a momentary overshoot at 65% and the peak normally occurring at 94% rpm, requires the flight crew to record the extent of the overtemperature condition and call for maintenance at the next layover where maintenance is available.

The action by maintenance personnel will be to check the TD valve null setting and adjust it toward decrease. If it is found on the subsequent engine start that the previous adjustment did not reduce the starting temperature to within limits, it will be necessary for maintenance to perform the starting overtemperature checks described in the applicable maintenance manual.

Over 850 degrees C

If the TIT exceeds 850 degrees C, excluding the peak occurring at 94% rpm, the flight crew should proceed as follows:

1. Shut the engine down by moving the condition lever to the GROUND STOP position (not FEATHER), and record the maximum TIT.

2. Allow the engine to cool to below 200 degrees C TIT before attempting to restart. The engine may’ be motored with the starter to cool it more rapidly, if necessary. When the engine has been cooled in this manner, wait one minute to make sure that the temperature has stabilized before initiating another start. Remember not to exceed the starter duty cycle.

3. If 850 degrees C is exceeded on the second start, shut down the engine and record the temperature, then call maintenance. Making another attempt to start the engine is not recommended.

Maintenance action will be to perform the starting overtemperature checks listed in the appropriate maintenance manual.

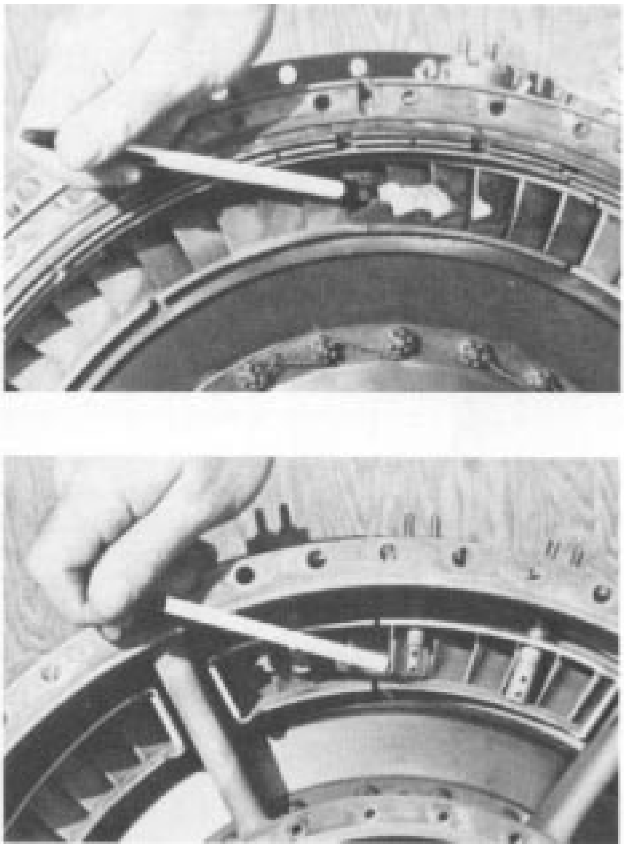
Over 965 degrees C

If TIT exceeds 965 degrees C during a start, shut down the engine, record the peak temperature and call for maintenance. Make no attempt to restart the engine. Maintenance action will be to perform an overtemperature inspection, consisting of a borescope visual inspection of the turbine section components.

If no damage is found in the course of these inspection procedures, all thermocouples must be removed, visually inspected, and electrically tested. If this inspection reveals no damage, maintenance can perform the starting overtemperature checks listed in the appropriate maintenance manual as required to correct the condition.

Thermocouples

The proper operation of the TIT indicating system has a critical bearing on the overall operation and service life of the 501/T56 engine. Malfunctioning or damaged thermocouples, or thermocouples of the wrong type, can lead to increased operating temperatures within the turbine and materially reduce engine life.



This turbine vane burn-through was caused by the use of thermocouples of the incorrect type.

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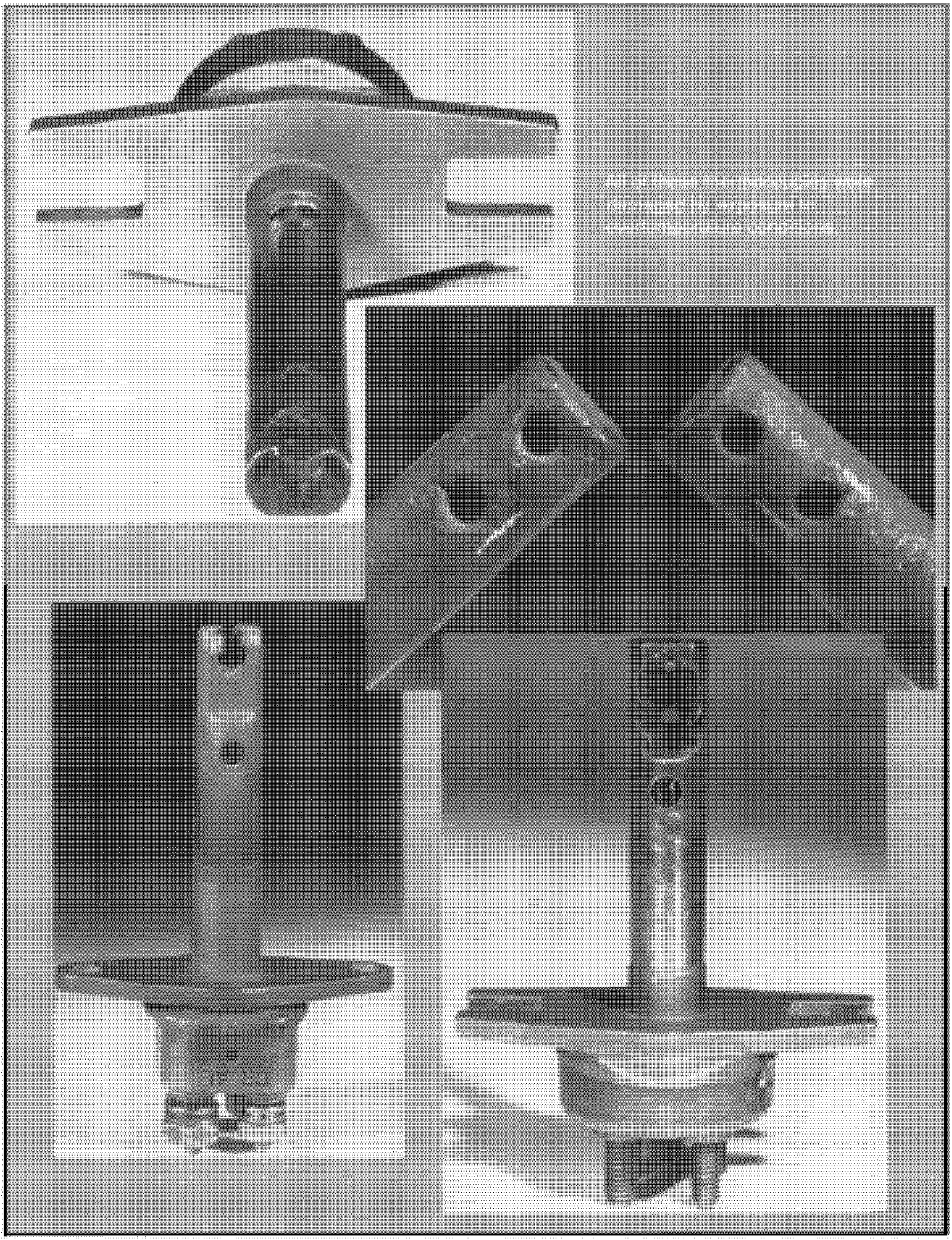

All of these thermocouples were damaged by exposure to overtemperature conditions.

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It is important not to become complacent about the accuracy of the TIT indicating system. It is possible to exceed the maximum allowable takeoff TIT limitation without knowing it if the engine has several deteriorated thermocouples. Under such circumstances, the operator would experience significantly reduced engine service life while mistakenly believing that the engine has been operated properly.

The engine TIT is measured by 18 thermocouples installed in the turbine inlet casing. Each thermocouple has two separate junctions that act as sensing elements. One junction of each of the 18 thermocouples is connected in parallel to provide an averaged signal to the TD amplifier.

The TD amplifier uses this signal to determine the actual TIT of the engine. The other junction of each thermocouple is also connected in parallel. Its signal becomes part of the averaged signal representing TIT that is displayed on the TIT indicator mounted on the engine instrument panel.

The Allison 501/T56 engine incorporates a system of multiple combustion chambers, which causes the temperatures measured at the turbine inlet to be somewhat nonuniform. A system of multiple thermocouples is used to compensate for these differences in temperature by sampling both the hotter and cooler areas and supplying an average temperature signal.

Since the temperature signal represents a value obtained by averaging the input from 18 different locations around the turbine inlet, it is very important that all of the thermocouples be functioningproperlyat all times. If any of the thermocouples fail, the signal being sent to the TD amplifier and the TIT indicator will be affected.

Thermocouples fail for a variety of reasons, including high resistance, open circuits, and probe tip damage. The failure of the thermocouple is an event that can initiate a whole series of further events, all of them bad.

Not surprisingly, thermocouples tend to fail most frequently at the hottest locations in an engine. The loss of a thermocouple in an engine hot spot will cause the average temperature signal sent to the TD amplifier and the TIT indicator to decrease.

Since the reduced temperature signal to the TD amplifier no longer satisfies the reference signal set by the throttle position, more fuel is directed to the fuel nozzles. The increased flow raises the TIT. and the fuel flow will continue to increase until the reference signal is matched by the signal from the remaining thermocouples.

Once this has occurred, the TD system will regard the situation as normal and the TIT indicator will display a normal temperature reading. But the situation is not normal. The apparent restoration of normal operation after the loss of a thermocouple has come at the cost of increasing the actual engine TIT.

The change in the actual TIT values that can result from having a defective thermocouple in the system is dependent upon its location, type, and the nature of the damage it has suffered. One thermocouple with the aft wall of the probe tip eroded, for example, can cause the true operating TIT to increase by up to 7.5 degrees.

As if this were not bad enough, thermocouple problems usually have cumulative effects. A sequence of failures involving five thermocouples with probe tip aft wall erosion can therefore raise the actual operating temperature of the engine by over 35 degrees at every power setting above crossover.

Such exposure to excessive operating temperatures is very destructive to engine components and will result in shortened service life.

Thermocouple Maintenance

Since properly functioning thermocouples play such a vital role in the engine control system, it is clear that a well-designed and conscientiously followed thermocouple maintenance program is of utmost importance.

All thermocouples should be regularly removed, inspected, and tested as described in T. 0. lC-130B-6 or SMP 515C, and the applicable Allison manual.

One of the most important things to remember about thermocouple inspections is to do it often enough. Finding more than three defective thermocouples in one engine at inspection time is a good indication that the period between inspections needs to be shortened.

When thermocouples are removed for examination, be sure to tag them as they are removed and keep a record of the positions where they were located. The condition of individual thermocouples often provides valuable clues about underlying problems involving other components.

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For example, thermocouples with badly burned probe tips or unusual carbon deposits suggest malfunctioning fuel nozzles or defective combustion liners, as does repeated thermocouple failures at the same location.

Inadequate maintenance of fuel nozzles can considerably shorten engine life. Allison recommends that all fuel nozzles be regularly removed, inspected, and functionally tested as part of an ongoing fuel nozzle maintenance program. An inspection interval of 1200 hours is suggested as a starting point for operators initiating such a program.

For operators not equipped to accomplish fuel nozzle inspection at the operating facility, the most practical approach will be to remove the nozzles and replace them with a set known to be serviceable every 1200 hours.

The removed units can then be sent to a properly equipped repair facility. Those that meet specifications after inspection, testing, and any necessary repairs can be returned to service in the next cycle.

Also, don’t overlook bad fuel as a possible source of thermocouple problems. Fuel contaminated by dirt or microorganisms can lead to thermocouple trouble by clogging fuel nozzles and altering fuel spray patterns.

Preventing Overtemperature Damage

Beyond strict adherence to the thermocouple maintenance and inspection procedures set forth in the authorized manuals, the best insurance against overtemperature damage brought on by malfunctioning thermocouples is vigilance on the part of the flight crew. Higher than normal fuel flow above crossover for a given TIT is one possible sign of malfunctioning thermocouples.

Another is higher than normal torque for a given TIT. Since fuel flow and torque are closely interrelated, an increase in fuel flow to raise the average TIT signal will also cause an engine’s torque output to increase. Careful attention to the fuel flow and torque indicators can pay substantial dividends in terms of timely detection of overtemperature conditions.

We have already seen that the TIT indicator will often not be a reliable guide to the actual TIT when thermocouple trouble is present. Usually the indicated TIT will be lower, sometimes much lower, than the true value.

You can make use of this fact to perform a simple test when problems in the thermocouple system are suspected. With all engines running and above crossover, and bleed air turned off, position the throttle levers so that torque and fuel flow for each are about equal. An engine with thermocouple damage will show a noticeably lower TIT than the other three.

Finally, an important thing to remember is that turbine engines never get better with age. They can only deteriorate as the combined effects of heat, erosion, sulfidation, corrosion, and wear gradually reduce their efficiency.

A 501/T56 engine that seems to be improving with age-producing more torque at the same indicated TIT, for example-should immediately attract your attention. Some things are too good to be true and this is one of them. It is very likely that there are problems in the TIT indicating system of this engine and prompt action is needed to prevent over temperature damage.

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