ORION
SERVICE digest

issue 29 January 1975

LOCKHEED · CALIFORNIA COMPANY

FRONT AND BACK COVERS

PATRON FORTY was commissioned 20 January 1951 at NAS North Island soon after the Korean conflict erupted. Four months later, trained and equipped with PBM Mariner aircraft, the squadron departed for Japan to commence its first operational deployment. During the months that followed, VP-40 patrolled the Tsushima Straits and flew missions over the Yellow Sea and the Sea of Japan.

CONTENTS

NOT FOR PUBLIC RELEASE

Lockheed
ORION
Service
Digest

In late 1952 the squadron deployed to Sangley Point, R. P., and conducted operations in the waters surrounding the Philippines. It was here that PATRON 40 acquired its motto "Laging Handa," which means "Always Ready" in Tagalog, the Philippine national language. For its operations during this tour, the squadron was awarded the Korean Presidential Unit Citation, Korean Service Medal, and the United Nations Service Medal. VP-40 then returned to North Island in April 1953, became the first West Coast squadron to transition to the P5M-1 Marlin, and assumed the nickname "Fighting Marlins."

With the end of hostilities in Korea, VP-40 began a series of tours in the Western Pacific that has continued to this day. In 1959 the Fighting Marlins worked closely with surface and air forces, both Nationalist Chinese and American, during the Matsu and Quemoy crisis and received the Armed Forces Expeditionary Medal for their outstanding efforts. Later that year the squadron changed its home port from North Island to Sangley Point, R. P.

Now at their new home, PATRON FORTY transitioned to the P5M-2 (SP-5B). During the next four years the squadron flew ASW coverage and shipping surveillance patrols in the Philippine area and over the South China Sea. The Fighting Marlins also conducted operations from the tender USS Floyds Bay, on occasion ranging south of the equator. In March 1964 the squadron returned to their old home port of North Island, and from there began yet another series of deployments to WESTPAC. Soon after their return to California, VP-40 was awarded the Battle Efficiency "E" for the 1963-1964 competitive cycle.

In 1965, FORTY conducted extensive operations from a seaplane tender off the coasts of Vietnam and Thailand. This was the first time since World War II that advanced-base tender operations were used under combat conditions.

VP-40's February 1967 deployment marked the Navy's last deployment of an operational seaplane squadron. After the squadron's last flight of a SP-5B on 6 November 1967, it moved to NAS Moffett Field to transition to the land-based P-3B Orion.

Outfitted and trained with their new aircraft, the Fighting Marlins deployed to Iwakuni, Japan in January 1969. The squadron was awarded another Armed Forces Expeditionary Medal for SAR operations conducted off the coast of North Korea during this tour, as well as the Vietnam Service Medal and the Republic of Vietnam Campaign Medal for flying advance-based patrols out of Cam Ranh Bay. April 1970 once again found PATRON FORTY deployed to Sangley Point, with a full-time detatchment in Thailand. The squadron's work in Operation Market Time during this tour won it the Republic of Vietnam Meritorious Unit Citation.

When VP-40 returned to Moffett Field in October 1970, it became the first operational P-3B squadron to have its aircraft fitted with DIFAR equipment. The squadron deployed to Okinawa in July 1971 and introduced DIFAR to WESTPAC. During this tour the Fighting Marlins conducted operations out of every allied country in the Pacific, from Australia to Korea. The squadron also participated in a weather modification project to help alleviate a drought on Okinawa. Its next deployment in August 1972 took FORTY to Japan, from where it again maintained detachments throughout WESTPAC.

In August 1973, VP-40 was selected to test a new concept in aircraft maintenance known as the Improved Maintenance Program (IMP). This program was demonstrated by the squadron, both at Moffett Field and at deployed sites, to be so effective that the Navy has decided to implement IMP on a fleet-wide basis. Meanwhile, the Marlins' well-honed operational skills won them the Battle Efficiency "E" for the 1973-1974 competitive cycle.

Today, PATRON FORTY has completed its transition from the P-3B to the modern computerized version of the Orion, the P-3C.

The Lockheed Orion Service Digest is published by Lockheed-California Company, Burbank, California. Material is not officially approved by the FAA, CAB, or any of the military services unless specifically noted. Military personnel are advised that direct use of the information in this publication may be restricted by directives in their organization. Material contained herein is not classified, but strictures against unauthorized and indiscriminate dissemination of military information apply. Republication of material is not sanctioned unless written permission is granted by Lockheed-California Company. Regulations require that republished material conform to the latest information and changes.

COPIES REQUIRED OR CHANGE OF ADDRESS – Please send your name; present address; occupation; your organization's name; and, if applicable, your old address as imprinted on a Digest envelope to:

YOUR LOCAL LOCKHEED-CALIFORNIA COMPANY SERVICE REPRESENTATIVE OR LOCKHEED ORION SERVICE DIGEST, DEPT. 64-18, BURBANK, CALIFORNIA 91520

editor | **WAYNE CRADDUCK**
assistant editor | **LUCILE HEMANN**
art and production by | **DEPARTMENT 84-23**

TURBINE INLET TEMPERATURE AND TURBINE LONGEVITY

by H. C. Mersereau
Supervisor of Service
Military Turboprop-Turboshaft Engines
Allison Division of General Motors

As the Patrol Plane Commander deplanes from a long flight, he smiles and comments to the Maintenance Chief . . . "Number two engine is a real tiger – puts out lots more horsepower than number three at the same TIT – uses a bit more fuel, but she really gets the job done." All hands are pleased to be complimented since it sure beats a squawk on the yellow sheet.

Unfortunately, they have misinterpreted the message conveyed by the engine instruments. Instead of being a "tiger," number two engine is asking for help. In this article we shall examine this situation from a technical viewpoint and determine what the engine instruments are trying to tell us. Later in the article we will also discuss engine "sulfidation" and suggest measures to minimize its effect. We shall omit discussions of such topics as temperature limiting operation versus temperature controlling operation, etc., since they are not within the scope of this article.

THERMOCOUPLES, TIT, AND THE TURBINE

GENERAL The T56 engine operates on a closed-loop electronically *controlled* turbine inlet temperature schedule above "crossover." (In this discussion, crossover is defined as the point of transition from one engine operating mode to another.) Below crossover the electronic trim system provides only temperature limiting protection. Crossover occurs at approximately 760°C TIT on T56-A-10WA engines (P-3A production aircraft) and at about 820°C TIT on T56-A-14 engines (P-3B and subsequent production aircraft, and some modified P-3A aircraft). With engine systems functioning normally, engine operation in the temperature-controlled mode produces excellent aircraft performance.

Two essential ingredients are required for the engine's electronic fuel scheduling system to function properly: (1) a "demanded" (or reference) turbine inlet temperature (TIT) signal, and (2) a feedback signal from the turbine inlet thermocouples that reflects actual TIT. The reference signal voltage is established by the engine temperature datum control (T. D. amplifier), the coordinator, associated relays and the engine and aircraft wiring harnesses. The magnitude of the reference signal is selected by the position of the engine power lever above crossover.

Due to T. D. system sensitivity, maintaining a scheduled TIT is analogous to balancing an object on the point of a pin. This can better be appreciated when you consider that the magnitude of the T. D. system controlling signal is in millivolts (1/1000 volt). For example, at full takeoff power a T56-A-14 engine produces about 4600 horsepower at a TIT of 1077°C with a controlling signal of less than 45 millivolts applied to its T. D. system. Moreover, the difference between the controlling signal at takeoff TIT (1077°C) and at maximum allowed continuous operation TIT (1010°C) is only 2.5 millivolts.

With the reference signal established, it is now up to the engine to "tell" the T. D. system when a TIT is achieved that satisfies the reference signal. The thermocouples installed at the turbine inlet produce the feedback signal that reflects the TIT. The T. D. control compares the feedback signal with the reference signal to determine when the demanded TIT selected by the power lever position is achieved.

ENGINE THERMOCOUPLES Thermocouples are devices made of dissimilar materials that develop a voltage (emf for the purist) when they are subjected to a temperature. In practical applications, a thermocouple will develop a voltage of known value for a given temperature exposure. Eighteen thermocouples are installed around the engine turbine inlet to measure the TIT. Figure 1 shows a typical thermocouple installation on the T56-A-10WA engine. Thermocouple installations on T56-A-14 engines are similar.

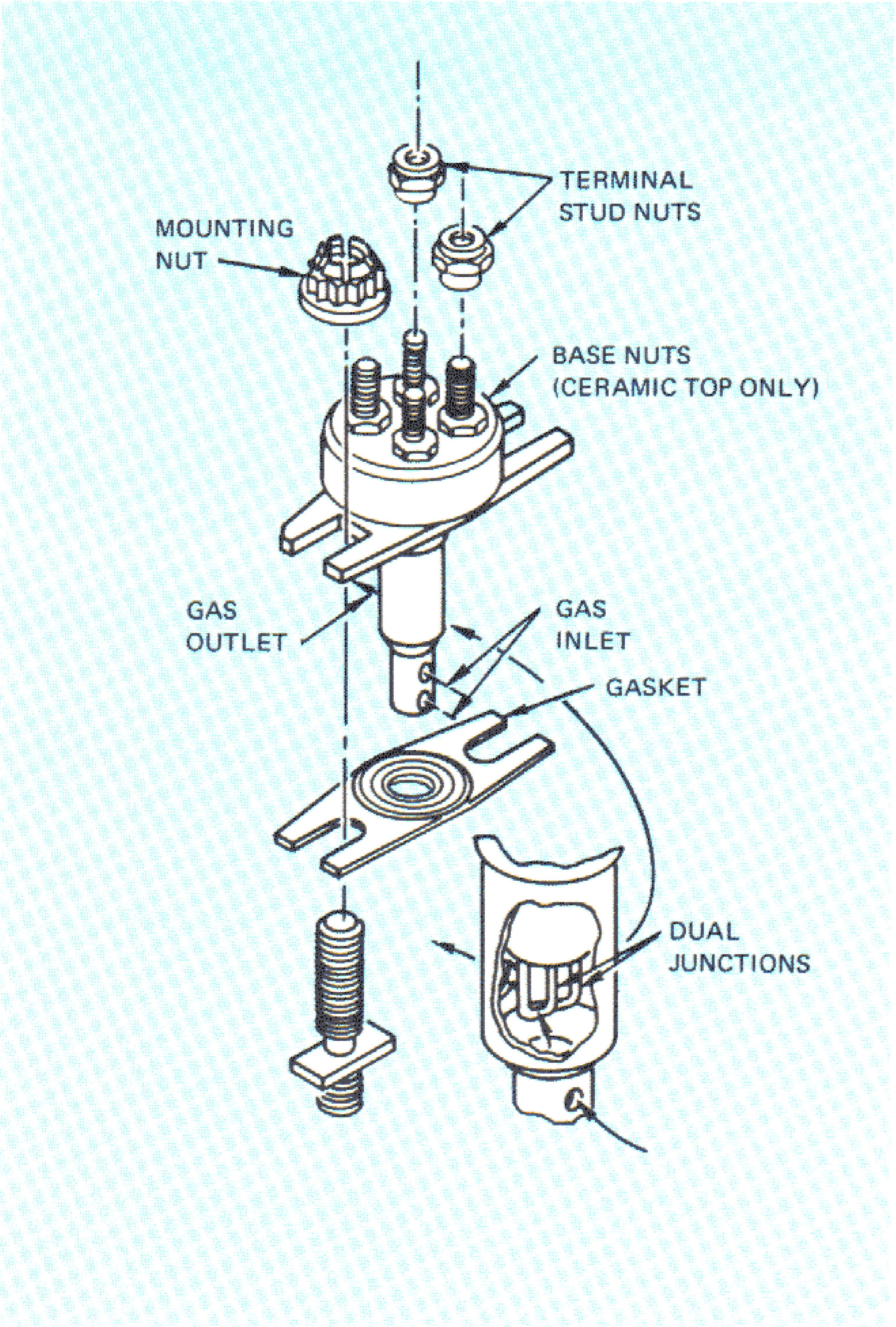


Figure 1 Exploded View of T56-A-10WA Engine Thermocouple and Attaching Parts

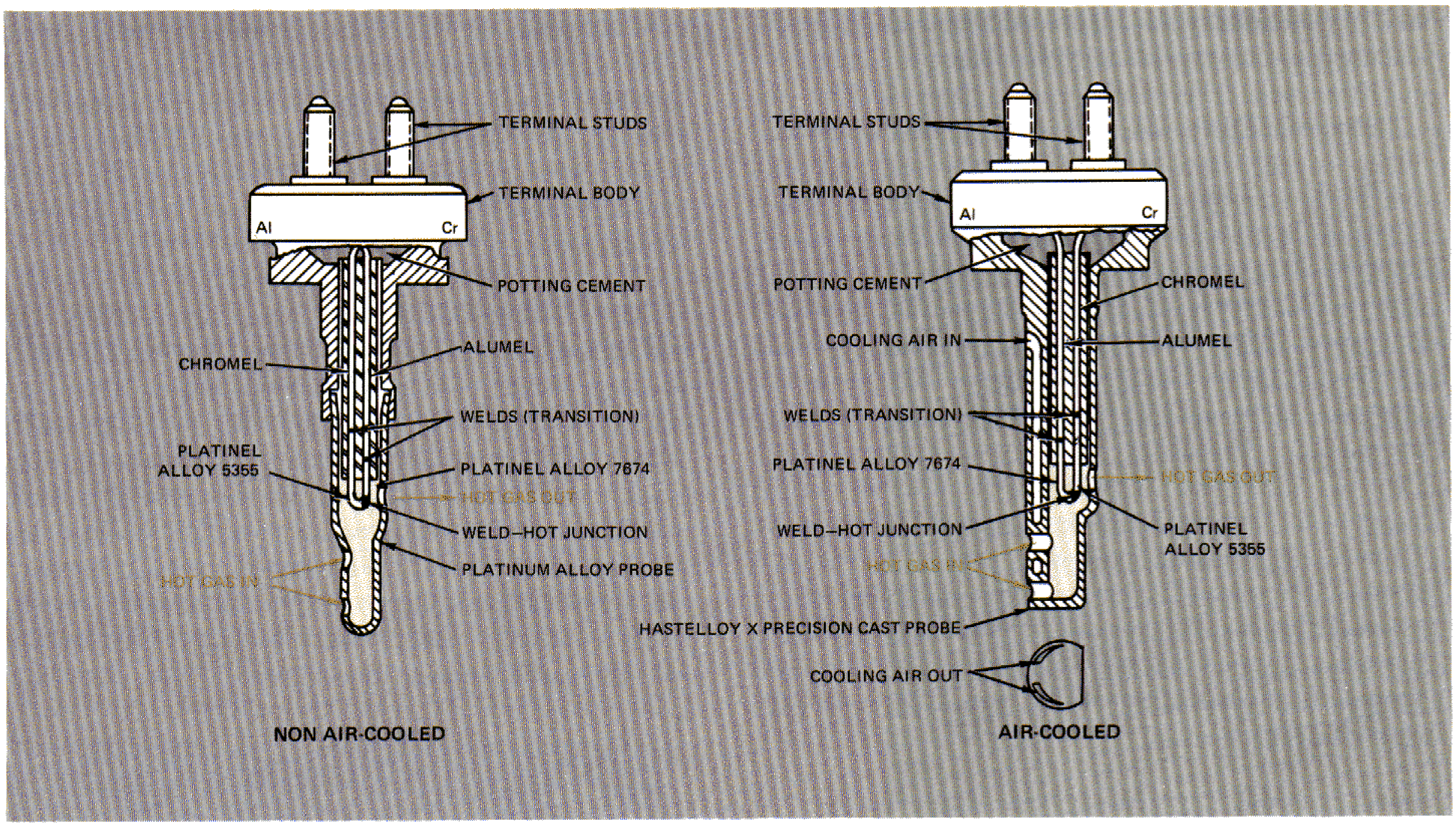


Figure 2 Cross-Section Views of T56-A-14 Thermocouples – Older Nonair-Cooled Type (l.) and Later Air-Cooled Type (r.)

Each thermocouple used in the T56 engine has two separate sensing elements, and hence it is called a "dual" thermocouple. One sensing element from each thermocouple is connected *in parallel* to a circuit that provides the feedback signal to the engine T. D. control. Thus, the signals from these eighteen thermocouple sensing elements are combined to provide an *average* measure of the TIT. Similarly, the other sensing element from each thermocouple is connected in parallel to another circuit, and their signals are combined to provide an *average* signal of the turbine inlet temperature to the TIT indicator in the flight station. Figure 2 shows cross-section views of the older non-air-cooled as well as new air-cooled thermocouples used on the T56-A-14 engines.

Air-Cooled Thermocouples Since the basic T56 engine was developed in the early 1950's, there have been significant improvements in thermocouple design. One such improvement is the air-cooled thermocouple installed on later production T56-A-14 engines. Due to the reduced body temperature of these air-cooled thermocouples, their operational life is estimated to be about four times that of the earlier non-air-cooled models.

At present, some T56-A-14 engines in service have non-air-cooled thermocouples, while others are equipped with air-cooled thermocouples. From the spares standpoint, the air-cooled and non-air-cooled thermocouples *on -14 engines* are physically and functionally interchangeable, thus one may be used to replace the other. Eventually, all non-air-cooled -14 engine thermocouples will be removed from service by attrition. Until then, no doubt there will be some T56-A-14 engines in service with a mix of air-cooled and non-air-cooled thermocouples. This condition is perfectly acceptable from an operational standpoint.

ENGINE OVERTEMPERATURE Nonuniform temperatures occur at the turbine inlet because of the short time span from spraying fuel from a nozzle, to fuel ignition, to introducing the hot gasses at high velocity to the turbine inlet. These hot gasses are not completely mixed, thus there are some stratifications (or islands) of hotter and cooler areas at the turbine inlet. The temperature averaging function of the two parallel thermocouple circuits compensates for these nonuniform temperatures.

Why, you may ask, get up-tight about a few defective thermocouples or hot spots? After all, there are eighteen thermocouples installed at the combustion liner outlet that produce *averaged* TIT signals for the T. D. amplifier and TIT indicator. In the following paragraphs we shall explain how this temperature averaging function can precipitate engine overtemperature problems if some thermocouples are defective, and these defects go unrecognized or undetected.

The two most common types of thermocouple damage that can cause engine overtemperature are open sensor junctions and broken probe tips. First we shall discuss what occurs when one or more thermocouples have open sensor junctions.

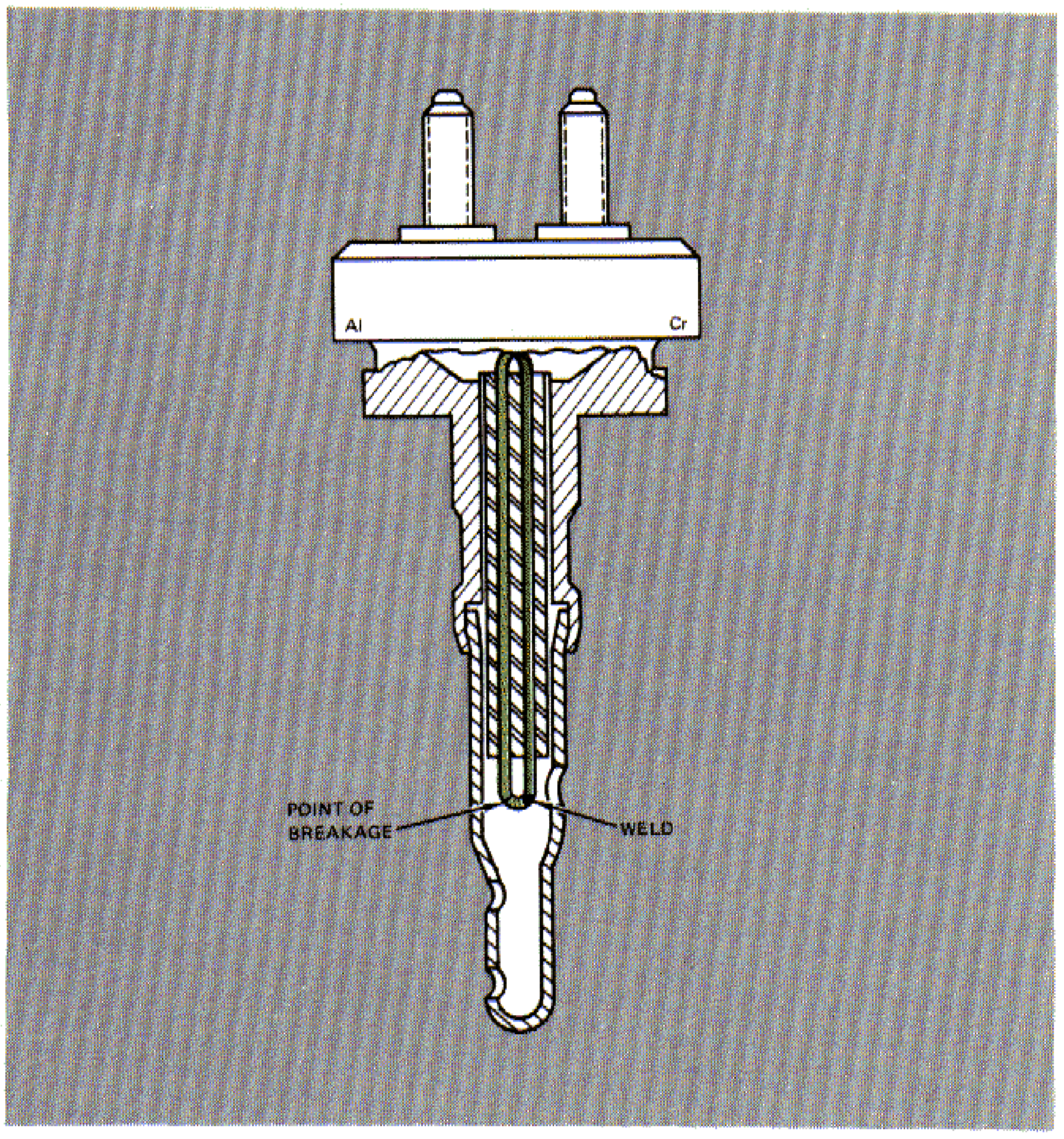
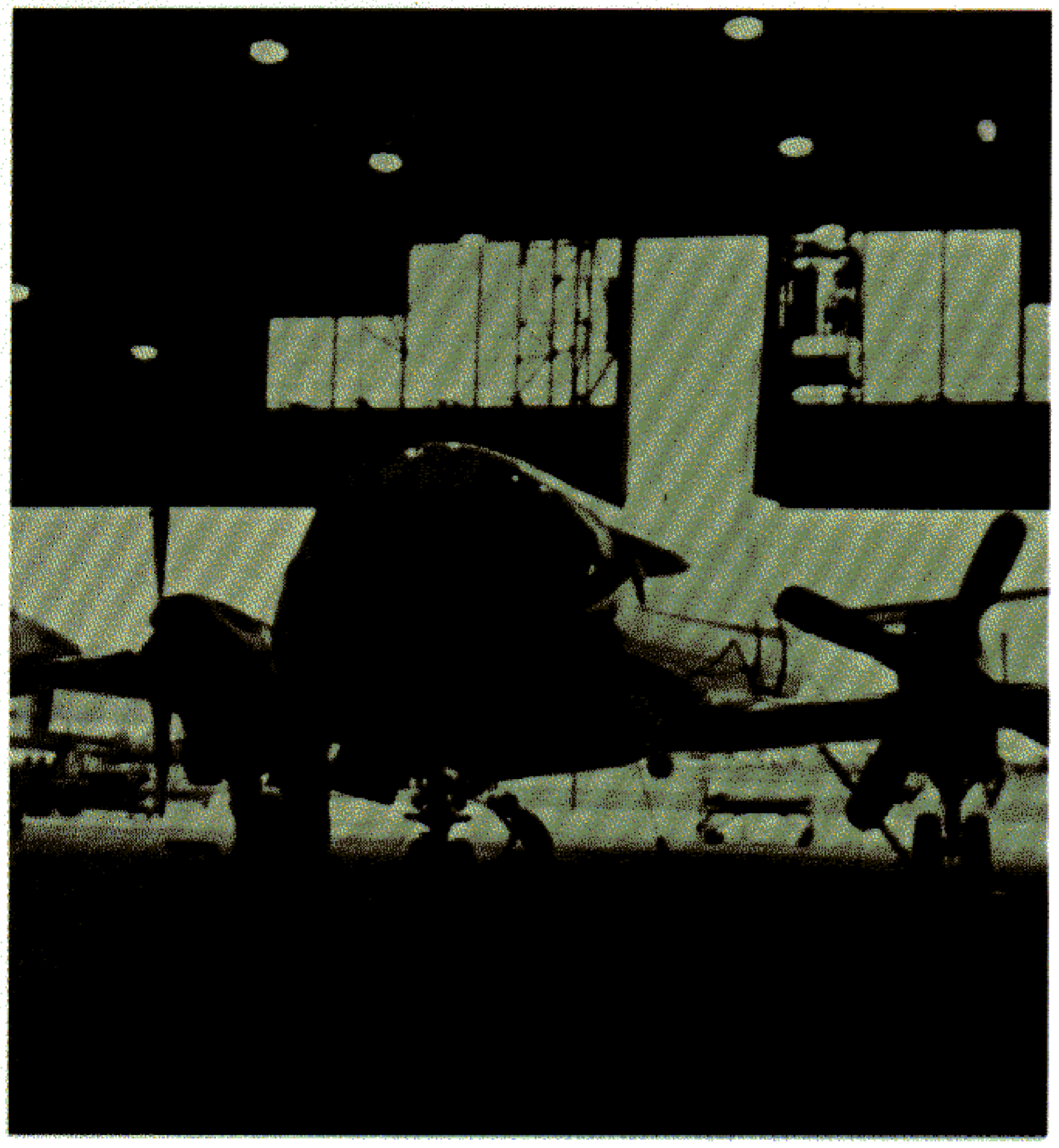


Figure 3 Thermocouple with Open Junction due to Breakage in Sensing Element. Point of Breakage is Shown near Weld of Sensing Element's Dissimilar Metals.



Thermocouples With Open Junctions Let us draw the reasonable assumption that the first thermocouple to fail will be the one at the hottest spot of the turbine inlet. (There are numerous possible failure sequences, but we shall comment on the simplest condition.) We shall further assume that both sensing element junctions of this thermocouple develop open circuits. Usually such open circuits are due to breakage of the sensing element, adjacent to the weld of the dissimilar metals (see Figure 3).

Since we have lost the highest signal inputs to each of the two parallel thermocouple circuits, the averaged signals to the T. D. amplifier and the TIT indicator are *reduced.* A reduced signal to the T. D. amplifier no longer satisfies the "demanded" reference signal, so the amplifier signals the T. D. valve to bypass *less* fuel. This action increases the fuel flow to the fuel nozzles and increases the turbine inlet temperature until the "demanded" average signal can be generated by the remaining thermocouple junctions. Thus, the demand of the T. D. system is satisfied, but now the engine is operating at a higher TIT. For the same reason, the TIT indicator presents a normal indication, but the *actual* TIT is higher than that indicated on the gage.

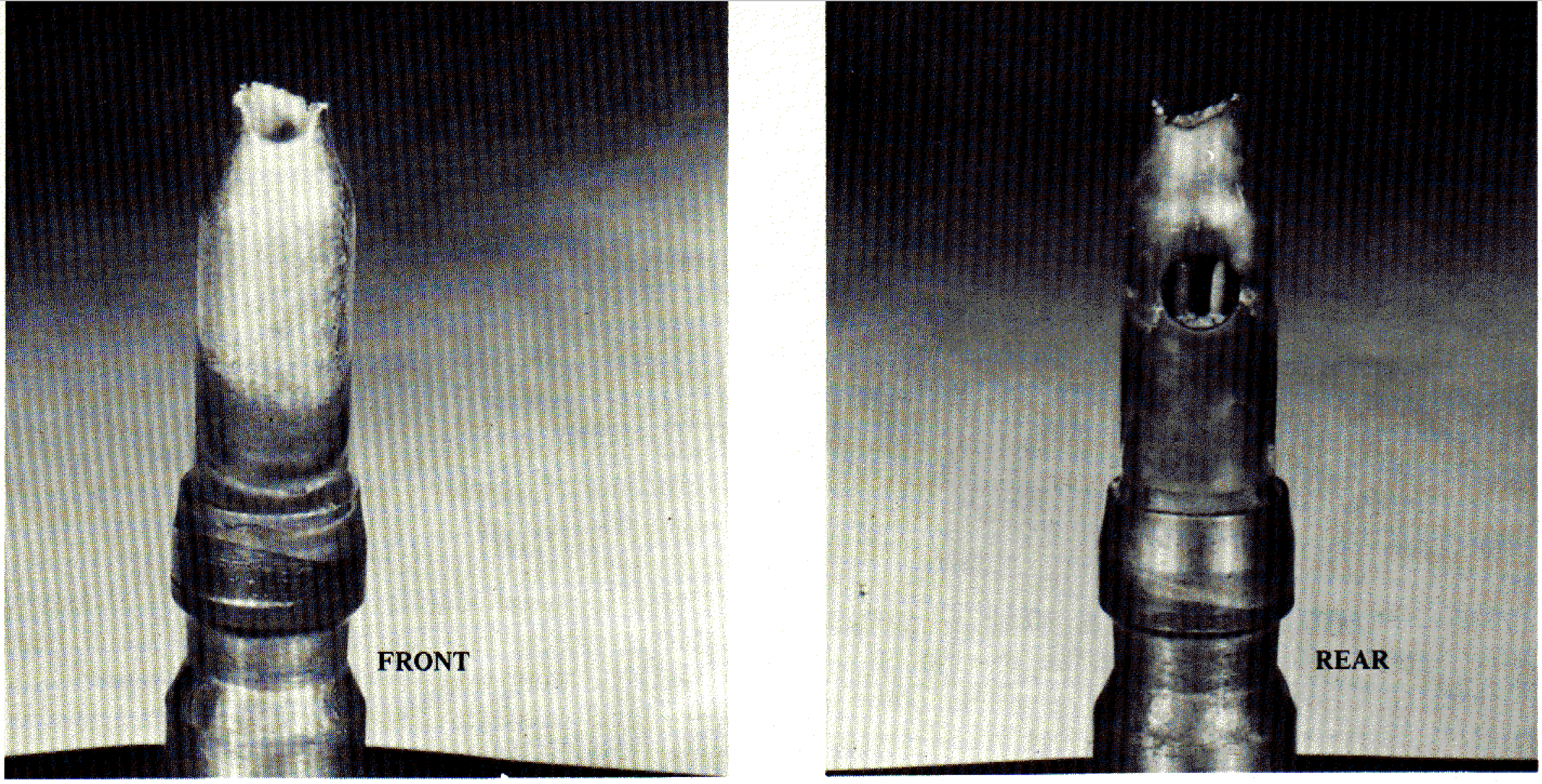
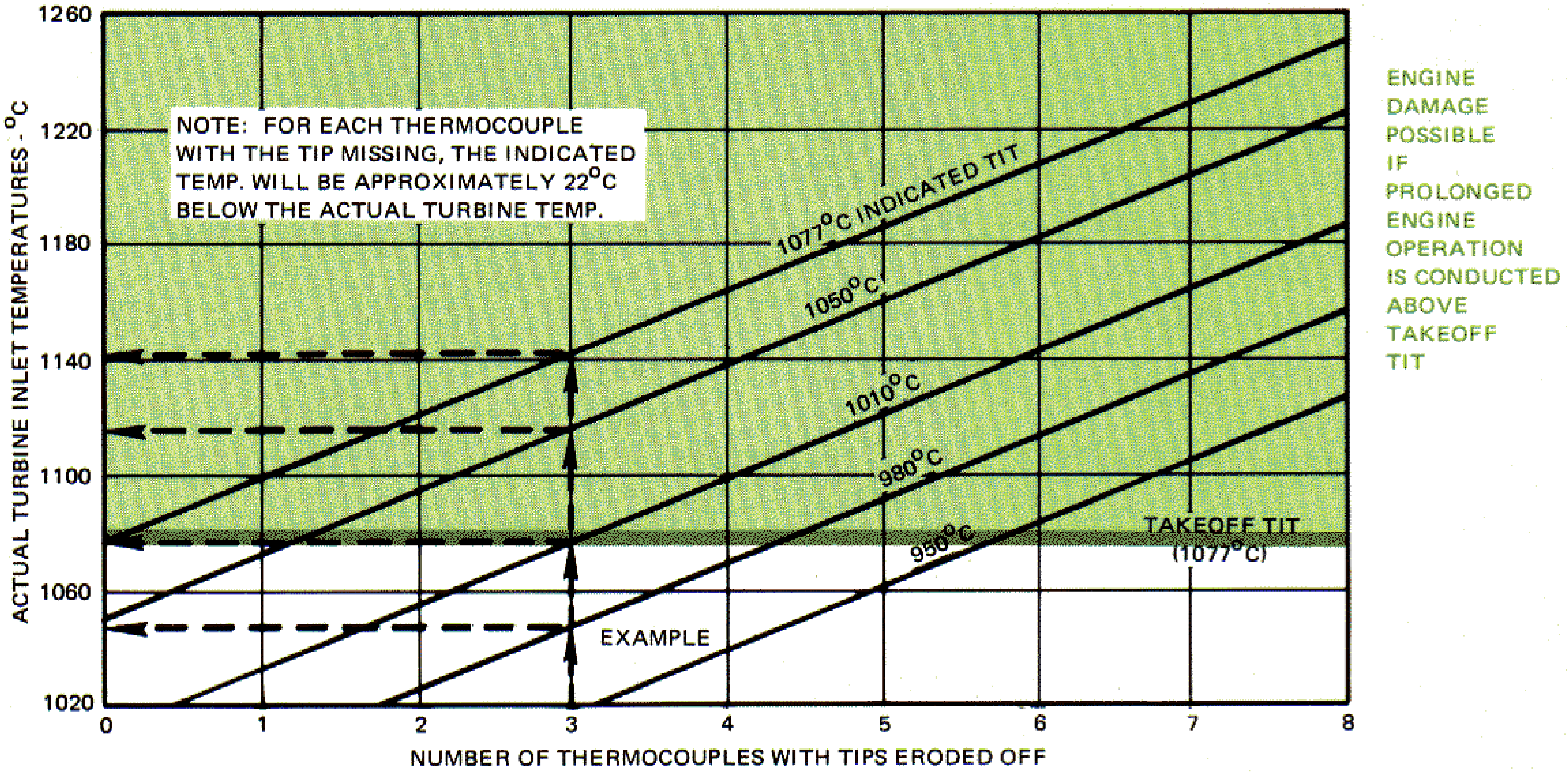


Figure 5 *Front (l.) and Rear (r.) Views of Thermocouple with Broken Probe Tip*

To illustrate this condition, let us assume that we have a properly functioning T56-A-14 engine, except that three of its thermocouples have probes with missing tips. Bear in mind that each thermocouple with a missing tip introduces an error of about 22°C below the actual averaged gas path temperature. Since the error is cumulative and there are three thermocouple probes with missing tips, the engine's indicated TIT is approximately 66°C *below* the actual TIT. Thus, at an indicated takeoff TIT of 1077°C, the actual TIT will be on the order of 1143°C. Even at an indicated "Normal" TIT of 1010°C, this engine's actual TIT would be approximating that for takeoff. Figure 6 shows the correlation between the indicated and actual TIT of an engine that has one or more thermocouple probe tips missing.

Figure 6 *Correlation Between Indicated and Actual Turbine Inlet Temperatures of T56-A-14 Engine with One or More Thermocouple Probe Tips Missing. Example Shows Difference at Selected Temperatures for Engine with Three Thermocouples with Missing Probe Tips.*



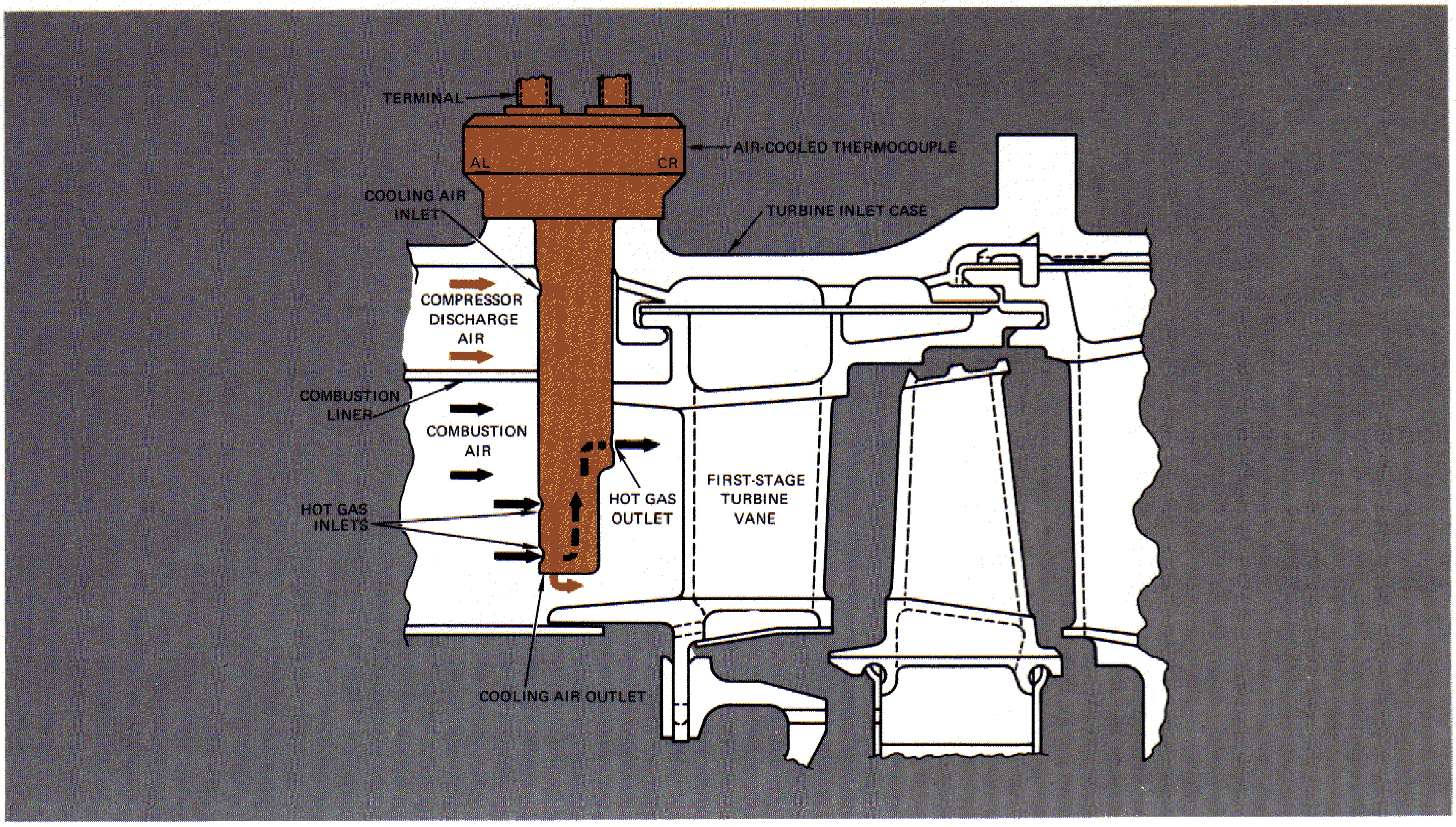


Figure 4 Location of Typical Thermocouple in T56-A-14 Engine Turbine Inlet. Location of Thermocouples in T56-A-10WA Engine Turbine Inlet is Similar.

Applying the logic that the next thermocouple to fail will be the "next hottest one," it is apparent that the engine can operate at ever-increasing *actual* TIT with a satisfactory *indicated* TIT. On the average, the actual TIT will increase approximately 6°C for each succeeding lost thermocouple. Thus, five open thermocouples would give us 1077°C indicated TIT on takeoff roll, while the actual TIT is over 1100°C. Obviously, this overtemperature is tough on the hardware.

Thermocouple Probes With Broken Tips Another defective thermocouple situation is even more serious than the previously described open-junction condition. In this case, the tip is completely broken off of the thermocouple probe but the sensing elements remain intact. This condition will introduce a mean average error in the signal to the T. D. amplifier that is approximately 22°C *low* for *each* thermocouple with a missing tip. Thus, the T. D. amplifier signals for more fuel – much more fuel – and again we have an overtemperature condition, but this time much greater in magnitude. Briefly, let's see why this occurs.

The T56 thermocouple assembly is a gas-sampling temperature sensing device installed at the turbine inlet as shown in Figure 4. Its bimetallic junctions are not immersed deeply in the hot gas stream, but instead are enclosed in a probe. The probe is designed to obtain samples from two different immersion levels in the gas stream, mix the samples, then direct the composite sample over the sensor junctions within the probe. After the temperature of the composite sample has been measured, the gas is exhausted from the downstream side of the probe.

If a thermocouple probe tip breaks off (generally the break is through one of the sampling holes as shown in Figure 5), the gas sample is not obtained from deep within the hot gas path where the temperature is greatest. Instead, the sensor junctions experience the relatively cool environment at the periphery of the combustion gas path. This causes the sensing elements to introduce an excessively low gas temperature signal to the parallel thermocouple circuits.

Thermocouple probe tip failure is usually due to erosion and is accelerated by exposing the probe to excessive temperatures. Eventually the probe tip can no longer withstand the forces in the high-velocity gas stream, and it breaks off. Since the probe is most vulnerable to erosion at the gas sampling inlet holes, these holes should be checked to determine the condition of the probe. Detailed inspection instructions are presented in NAVAIR 02B-5DD-6.

OVERTEMPERATURE SYMPTOMS On a power extraction-type turbine engine the thermocouples are located at the turbine inlet where we want to control the engine temperature, not in the exhaust where the drastically reduced temperatures would produce control signals that are ineffective in measuring turbine inlet temperature. Thermocouples that are in good condition will give accurate control signals, but deteriorated or defective thermocouples will give inaccurate signals that can create all kinds of grief. The engine will try to tell us when it needs attention by giving abnormal indications on the cockpit instruments. However, we must recognize and interpret these symptoms so that timely corrective action can be taken.

TIT is merely a very remote indication of that which propels the aircraft through the air – namely, propeller thrust. For P-3 Aircraft, the best indication of thrust is *engine horsepower,* since delivered horsepower is the ingredient that really determines what blade angle is assumed by the propeller to deliver thrust. Thus, the engine horsepower indicating system, *properly and accurately calibrated in accordance with NAVAIR 01-75PAA-2-4,* is the most accurate engine power indicator in the flight station. Some flight personnel always use horsepower to set the power levers, using TIT as an upper limit that shall not be violated. The engine manufacturer, Detroit Diesel Allison, has recommended this practice for years.

Careful attention to the fuel flow and horsepower gages will pay dividends in the timely prevention and/or detection of overtemperature conditions. The tipoff that an engine has an overtemperature condition is that the engine is flowing more fuel than it should above crossover, and thus is generating more than normal horsepower for that power lever setting. Often the engine will stick out like the proverbial sore thumb as in the example at the beginning of this article. One such case came to light last year when a turbine came all "unglued." A review of the yellow sheets revealed that the engine instruments had been displaying the classic symptoms of defective thermocouples many hours before turbine failure.

"Trend analysis" connotes a great deal of record keeping, but it can pay off. There has never been an engine that was "better" at 1000 hours time since last overhaul (TSLO) than it was at zero hours TSLO. Due to erosion, corrosion, etc., an engine does not appreciate in performance as it gets older, it can only depreciate. So, if one of *your* engines gets "stronger," *you had better take a look.*

THERMOCOUPLE INSPECTIONS In practice, thermocouples are not the easiest things to inspect. Consequently, there is the temptation to defer this task even though engine instrument indications may demand it. From the preceding discussions, the detrimental effect of damaged thermocouples on an engine is apparent, thus the need for timely thermocouple inspections and maintenance cannot be overemphasized. Detailed maintenance and inspection instructions are presented in NAVAIR 01-75PAA-2-4, NAVAIR 01-75PXX-6-X4 (Activities transitioned to P-3 Improved Maintenance Program) or NAVAIR 01-75PAA-6-3 (Activities not employing the Improved Maintenance Program), NAVAIR 02B-5DD-6-1, and NAVAIR 02B-5DD-6-2.

THERMOCOUPLE REPLACEMENT If, during maintenance operations, it becomes necessary to replace a thermocouple, *be certain that the defective thermocouple is replaced with the correct spare.* Thermocouples installed on T56-A-10WA and T56-A-14 engines are physically, *but not functionally*, interchangeable. If an engine is equipped with the wrong type of thermocouple, erroneous temperature signals will be sent to its T. D. control and TIT indicator. Use of erroneous TIT signals to control engine operation can result in degraded performance or damage to the engine.

Consult NAVAIR 02B-5DD-4 Illustrated Parts Breakdown for the correct thermocouple part number.

Up to this point, this article has been predominantly directed toward the T56-A-14 engine. However, the same remarks also apply to the T56-A-10WA engine. The -10WA engine does not operate at TIT ratings as high as those of the -14 engine, but neither does it have an air-cooled turbine or air-cooled thermocouples. Consequently, there probably have been as many (if not more) damaged thermocouples on -10WA engines as there have been on the -14's. The result is equally serious.

Lockheed
ORION
Service
Digest

SULFIDATION

Over the years the aircraft engine industry has introduced superalloys to turbine applications in order to keep pace with successively more demanding requirements for higher engine operating temperatures. With these exotic materials have come special problems, one of which is a form of high-temperature corrosion called *sulfidation*. Several other terms have been used to describe this phenomenon – "hot corrosion" has been applied to the process of sulfidation, while "black plague" and "black rot" were a couple of early names that reflect the appearance of the material under attack.

Today we know that sulfidation is the corrosive attack of certain base elements in some superalloys by sodium and sulfate ions when these alloys are subjected to high temperature. It is most pronounced at the first stage of a turbine where the environment is most harsh. Figure 7 shows examples of advanced sulfidation of first stage turbine blades from a T56-A-10W engine. The blades appear to be blistering, scaling, or delaminating, and the material loss from the blade coincides with the combustion gas path.

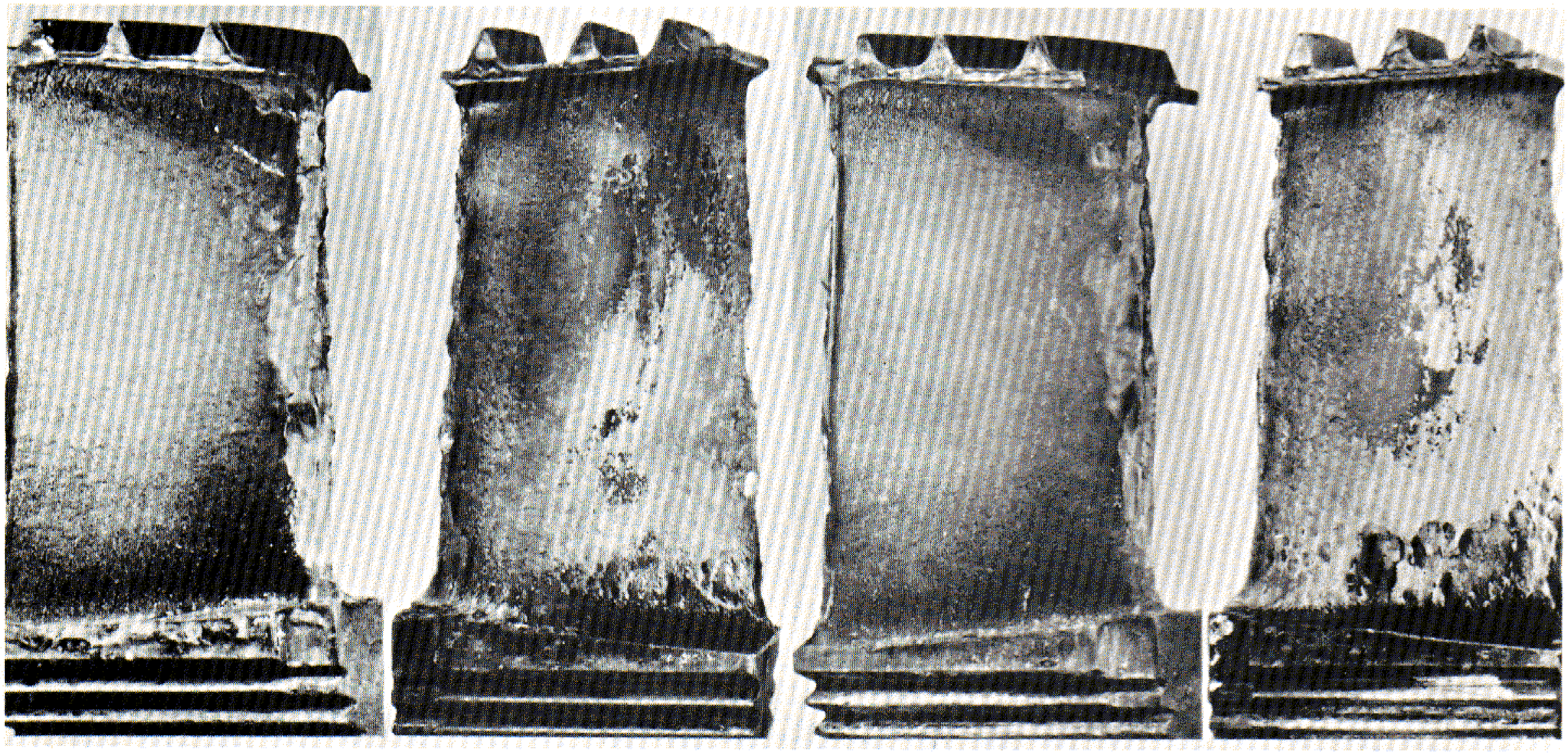


Figure 7 First Stage Turbine Blades from T56-A-10W Engine that have Experienced Advanced Sulfidation

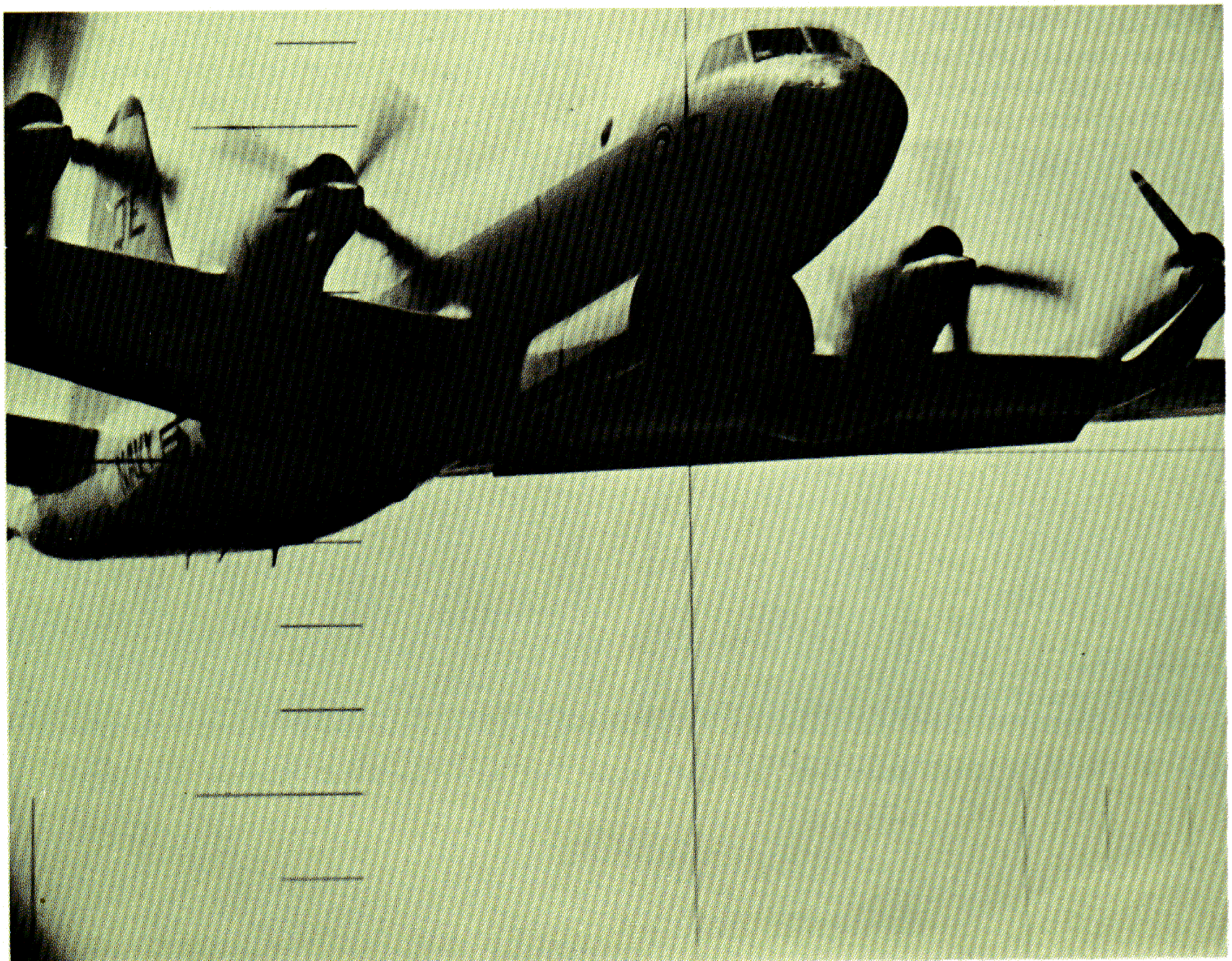
One obvious solution to sulfidation would seem to be exclusion of these ions from the environment of the alloys. However, this approach proves to be impractical when it is applied to aircraft turbine engines. Sodium and sulfate ions are present in sea water and coastal atmospheres, available from sulphur in jet fuel, found in aircraft cleaning solutions, exist as sulphur dioxide in the atmosphere, and are dumped into the atmosphere as sulphur-bearing particulates from industrial waste. Thus, when a turbine-powered aircraft is parked at an airport located adjacent to the seashore and in the vicinity of a large industrial city, its engines are going to be exposed to plenty of sodium and sulfate ions. The engines are further exposed to these ions during routine long, low-level flights over the ocean.

Another solution is to make the turbine components from materials that are immune to sulfidation. This has prompted the continuing search for high temperature materials with better corrosion resistance characteristics. Protective coatings likewise are continuously being evaluated.

TURBINE MATERIALS The materials composition of turbine blades and vanes differs due to the vastly different function that those components must perform. Early T56 engines had the forward stages of turbine blades made from GMR-235 alloy and vanes made of X-40 alloy. These were the best materials obtainable at the time and both were resistant to sulfidation.

Subsequently, GMR-235 Alloy blades in the turbine forward stages were superseded by blades of a stronger material known as Alloy 713C. This stronger alloy was originally used for the forward stages of T56-A-14 turbine blades and vanes, and is currently used for T56-A-10W turbine blades.

Alloy 713C is a nickel-base superalloy with superior strength at high temperatures, but without protection it has proven to be vulnerable to sulfidation. Once that sulfidation was identified as a basic problem area, efforts were directed to develop a protective coating for Alloy 713C components. As a result, General Motors developed a process known as "Alpak."



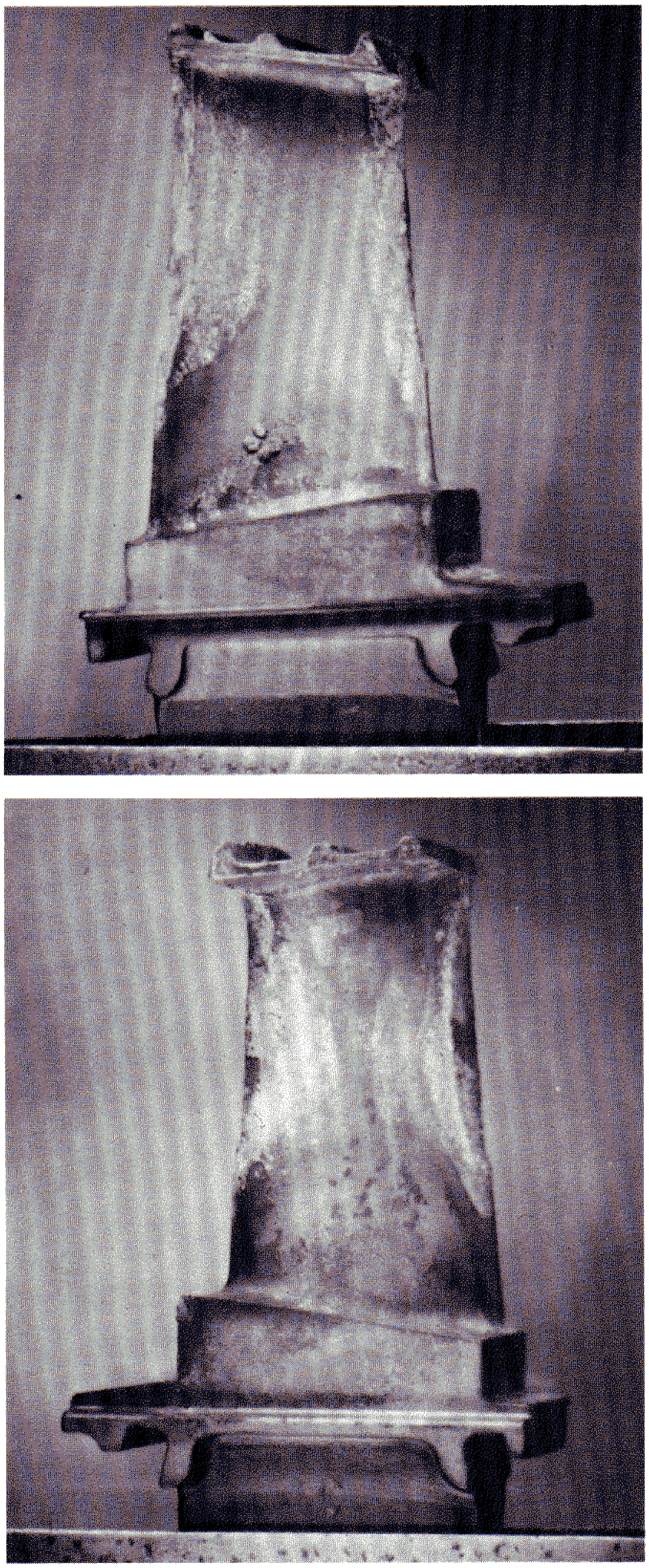


Figure 8 Views of Alpak-Coated Turbine Blade with Sulfidation Damage. Blade was Removed from the First Stage Turbine of a T56-A-14 Engine.

Alpak Protective Coating Alpak is a diffused coating of aluminum that is applied to Alloy 713C turbine parts to provide a protective barrier between the component and sodium/sulphate ions. This coating has demonstrated that it is an effective means of protection, extending the service life of Alloy 713C turbine parts by a factor of 4 or 5. Although the Alpak coating will eventually erode, it can be reapplied to a blade or vane wherever approved facilities exist. NARF Alameda has established an in-house capability to reapply Alpak protective coatings. Any T56 turbine processed by NARF Alameda after 1 April 1974 should have Alpak applied, as required, to the appropriate hardware.

Naturally, if the eroded Alpak coating is not renewed, the bare portion of the part will be exposed to sulfidation. Figure 8 shows views of a first stage turbine blade made of Alpak-coated Alloy 713C that is from a T56-A-14 engine. Both the concave and convex sides of the blade are shown, and material loss due to sulfidation is readily apparent. Note that sulfidation generally attacks the airfoil edges first, since the Alpak coating on these surfaces is subjected to the greatest erosion. After the protective Alpak coating has been removed by erosion, sulfidation of the base material can commence.

Figure 9 shows the front and rear view of an Alpak-coated Alloy 713C first stage turbine vane segment with sulfidation damage that was removed from a T56-A-14 engine. A borescope inspection revealed the obvious material loss due to sulfidation from the vane's leading and trailing edges, where the Alpak coating had eroded. Further examination of the leading edge also revealed a crack that leads to the internal cavity of the air cooled vane. Metallurgical analysis of this vane also established that it had been subjected to excessive temperature for an unknown period during the engine's service life.

Recent Developments in T56 Turbine Materials Alloy 713C was followed by the introduction of a newly-developed blade material known as Martin Metal Alloy M246. Turbine blades made of MAR-M246 are a distinct improvement over the older Alloy 713C blades for two reasons. First, MAR-M246 has a greater strength at elevated

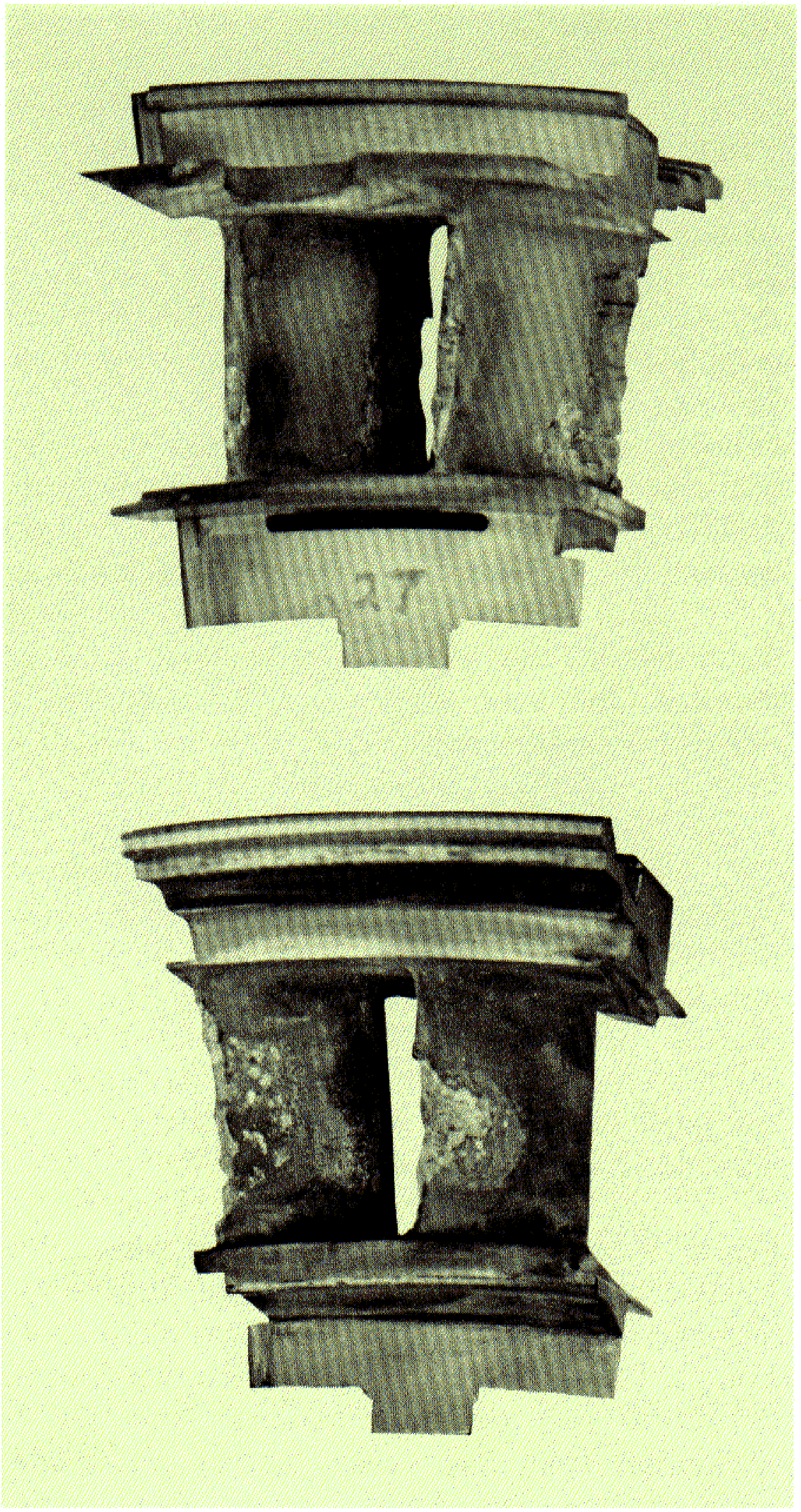


Figure 9 Views of Alpak-Coated Alloy 713C Turbine Vane Segment with Sulfidation Damage. Vane Segment was Removed from the First Stage Turbine of a T56-A-14 Engine.

temperatures, and second, there is a better marriage between the Alpak protective coating and MAR-M246 blades than there is between the Alpak coating and Alloy 713C blades. The U. S. Navy accepted first stage turbine blades made of this alloy for the T56-A-14 engine in June 1970. All subsequent production T56-A-14 engines have been equipped with Alpak-coated MAR-M246 turbine blades, and blades of this material are being retrofitted into T56-A-14 turbines of earlier manufacture at rotor overhaul by incorporation of T56 Power Plant Change 53.

The present in-service first stage turbine blades in T56-A-10WA engines are made of Alpak-coated Alloy 713C, while the first stage vanes are made of Alpak-coated X-40 alloy. X-40 material is a cobalt-base alloy and is thus very highly resistant to hot corrosion. At turbine inlet temperatures normally encountered in the T56-A-10WA engine the X-40 first stage turbine vanes have been quite satisfactory, but these vanes are subject to thermal cracking when they are exposed to overtemperature conditions. Recent advances in vane design and the application of cooling air flow have allowed first stage turbine vanes for the T56-A-14 engine to be fabricated from X-40 alloy. Installation of Alpak-coated X-40 alloy first stage turbine vanes on production T56-A-14 engines is anticipated in mid-1975, followed by installation on in-service -14 engines on an attrition basis.

We have discussed the evolution of T56 turbine blade material from GMR-235 through Alloy 713C to MAR-M246 (of which the current -14 first stage turbine blades are made). Looking to the future, the U. S. Navy is operating five service test "rainbow turbines," so called because they have a mix of turbine materials, including INCO-738, under the cognizance of COMPATWINGSPAC.

Among other related industry developments, the U. S. Air Force has approved use of turbine blades made of INCO-738 alloy in their counterpart of the T56-A-14 engine. An Alpak-coated blade of INCO-738 is even more sulfidation-resistant than one made of Alpak-coated MAR-M246 after the Alpak coating has been removed by erosion.

Advances in high-temperature metallurgy are often reflected by increased turbine engine life. Many can still recall when achieving 50 hours time before overhaul on an aircraft gas turbine engine was unusual. Presently we have maximum operating times (MOT) of 5000 and 6000 hours respectively for T56-A-10WA and -14 engine power sections, with the MOT for gear boxes presently at 8000 hours and heading for a target maximum operating time (TMOT) of 10,000 hours. Furthermore, the search continues for better materials to continually improve turbine longevity.

SULFIDATION MINIMIZATION Earlier we stated that there are several sources of sodium and sulfate ions – the atmosphere, fuel, cleaning solutions, etc. Little can be done about the atmosphere at the location from which the squadron operates. Likewise, the operator must use fuels that are specified by MIL-SPEC and standardized throughout the Fleet. Thus, the actions by a squadron to combat sulfidation and promote turbine longevity must be maintenance and operations oriented.

Maintenance Actions The following maintenance actions are useful sulfidation control measures.

Use Engine Closure Plugs On Parked Aircraft At coastal locations, salt-laden air will enter the front and rear engine openings of turbine-powered aircraft unless air inlet and exhaust closures are used. Sulfidation-producing ingredients can deposit on the turbine blades and vanes while an aircraft is parked, then later, when the engines are operated, the major damage can occur. Static accumulation of salt deposits in engines can be effectively reduced by proper use of air inlet and tail pipe plugs.

Use The Proper Engine Washing Procedures The P-3 probably gets bathed more than any other aircraft in the Navy's inventory, so let's examine the subject of "water wash" and see where engine and airframe requirements differ. A taxi through the "bird bath" does the job intended for the airframe – it washes salt and other deposits from the aircraft, engine air inlet housing, and the front of the compressor. However, it does *nothing* to combat turbine sulfidation and does *not* satisfy the cleaning requirements of the engines. In fact, under certain conditions, the "bird bath" could be detrimental to the engines.

Detroit Diesel Allison (DDA) recommends that water with more than 35 parts per million impurities *not* be introduced into the inlet of an operating engine. Although the engine can probably tolerate water with a slightly higher level of impurity, the limit cannot be defined without performing a costly test program.

If the engine gas path is to be washed, DDA recommends that the engine be *motored* with the starter, and that the water introduced at the inlet be of drinkable purity. The temperature of compression is not enough to boil off the water during an engine *motoring* wash, as would be the case if the engine were running.

An engine motoring wash is of primary benefit to the engine compressor, but it can also help combat turbine sulfidation to a minor degree if performed on a timely basis. After the last flight of the day and with the engine cooled down, an engine motoring wash will help dispel any sulfate ions from the turbine that have not reacted with the vanes or blades during that day's operation. If an aircraft has been parked for hours (or days) in a salt-laden environment, the salt and sulfate ions that have accumulated during the interim should be flushed from the engine gas path *before* subsequent engine operations are conducted. An engine motoring water wash procedure for T56 engines is presented in USAF T. O. 2J-T56-101. This publication also lists an approved wetting agent for the engine gas path that can be used during the engine motoring wash procedure. A Navy-published motoring water wash procedure is expected in the near future.

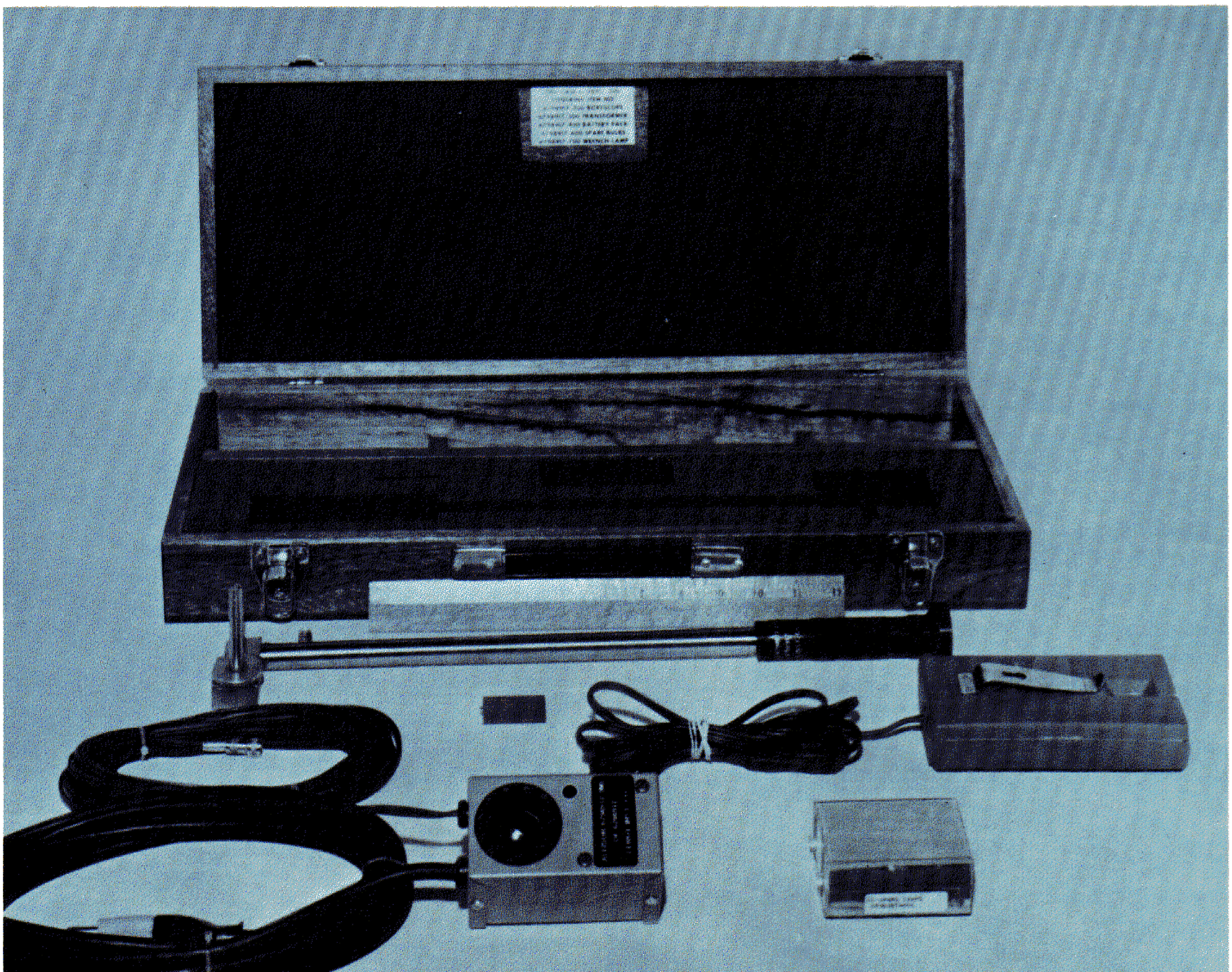
Use Engine Closure Plugs When Washing The Aircraft With Detergents Occasionally it is necessary to scrub the aircraft with a detergent. Since detergents are usually loaded with sulfates, these ingredients should not be introduced into the engine gas path. Therefore, the engine openings must be masked with appropriate closures before the aircraft is scrubbed with detergent.

Perform Regular Inspections Of The Engine Hot Section As Specified By The Applicable Periodic Maintenance Requirement Publications Fleet maintenance personnel report that the latest borescope kit, P/N 6798917 (FSN 6650-438-3982), can be a valuable tool for inspecting the T56's turbine first stage and the combustion liners. They state that the first stage blades and vanes and every liner position can be viewed with the borescope through the thermocouple mounting holes. The borescope kit is shown in Figure 10.

Use Alpak-Coated Parts For Replacements When a turbine is repaired by an AIMD, be certain that it is rebuilt with vanes that have been properly coated with Alpak, or soon the engine may be back in the shop with sulfidation. Likewise, use only a turbine rotor that has no indications of sulfidation, because once sulfidation starts it progresses rapidly. Since NARF Alameda now has the capability to apply the Alpak protective coating to T56 turbine components, T56 turbines that are subsequently rebuilt by NARF should have first and second stage blades and vanes protected by Alpak.

Operational Recommendations Engine sulfidation can be minimized by operating the engines at lower power settings when one has a choice. This reduces the turbine inlet temperature which, in turn, reduces the sulfidation factor and means longer life for the components in the turbine gas path. Of

Figure 10 P/N 6798917 Borescope Kit



course, the total range of engine power and TIT set forth in the NATOPS Flight Manual is *always* available when you need it. Essentially, it boils down to running a professional cockpit at all times. When you *need* high power, *use it*; when you don't need high power to accomplish your mission, *"cool it."*

Sulfidation Factor is a measure of material weight loss vs. TIT. In the past, we have tried to relate sulfidation factor to turbine materials and TIT by a simple curve, but this correlation has not been entirely satisfactory. Actually, the picture is considerably more complex because three variables exert considerable influence on the sulfidation factor – namely, the exposure time of the metal to sulfate ions, the *actual* metal temperature (not necessarily the TIT gas temperature)*, and the sulfate ion concentration. It suffices to say that the sulfidation rate, holding all other factors constant, is exponentially related to actual metal temperature. If the Alpak coating has eroded from a turbine's blades or vanes and sulfidation is present, the sulfidation rate in the cruise TIT regime can be cut approximately in half with a 30 to 40°C reduction in metal temperature. Indeed, for components whose Alpak coating has eroded, *any* available power reduction provides measurable sulfidation reduction.

The NORMAL RATED Power Setting on the T56-A-14 engine is rated at a TIT of 1010°C. (The corresponding TIT setting on the -10WA engine is 932°C.) We stress that the term "NORMAL RATED," as it relates to an engine power rating, is a model specification term that defines the *maximum* continuous rating at which the engine may be operated without a time limit (i.e. 5 minutes, 30 minutes). Thus, it should be emphasized that NORMAL RATED is a *maximum* value for continuous engine operation, but temperatures below NORMAL RATED can be used for continuous cruise as applicable.

Like any piece of hardware, the engine's turbine responds favorably to kind treatment. Engine operation at lower TIT's, when feasible, will promote longer turbine service life. By reducing the cruise TIT on a -14 engine from 1010°C to 970 - 980°C, the sulfidation factor on bare turbine materials is cut approximately in half; the sulfidation factor is reduced further when cruise TIT is further reduced.

Other gains also are realized when an engine is operated at reduced TIT. The turbine vanes suffer less from thermal cracks, and other turbine components also suffer less from general wear-and-tear. In other words, engine operation at reduced power (when acceptable to mission accomplishment) derives longer life from the engine hot section components. This keeps more P-3's in an "UP" status for less maintenance man-hours at a reduced total cost for parts.

Lockheed
ORION
Service
Digest

CONCLUSION

In this article we have discussed the relationship between the T56 engine's turbine inlet temperature and its turbine longevity. One aspect of this relationship is the effect of damaged thermocouples on overall engine condition, while another is that of engine sulfidation. Recognition of abnormal engine instrument indications is the best clue that the thermocouples have sustained damage, especially note the relationship between engine horsepower vs. TIT vs. fuel flow. Trend analysis is another useful tool in monitoring engine condition. Once thermocouple damage is suspected, prompt maintenance action is vital.

We have also suggested measures that can be employed by operational and maintenance personnel to minimize engine sulfidation.

---

* *For example, at takeoff power on the T56-A-14 engine, the first stage turbine vane metal temperature is approximately 120°C less than the indicated TIT.*

Maintenance measures are primarily directed toward excluding corrosive agents from the turbine's environment. Operational measures can be summarized as follows:

o *When you need power, use it to the maximum rating – as necessary.*

o *When mission requirements can be met with a lower power, cool it!*

In the final analysis, the cockpit crew is the most influential variable in the life-cycle cost of engine ownership. Recognize how economy can be achieved, then practice it.

Lockheed ORION Service Digest

ERRATA: Orion Service Digest Issue 28, December 1973

Page 6, first complete paragraph, left-hand column, the second sentence should read: "By convention, lines of force emerge near the geographic South pole and enter near the geographic North pole."

Page 10, first paragraph, right-hand column, the first complete sentence should read: "A full throw of all of the controls sequentially (i.e., ailerons, elevators, and rudder) should not generate a noise greater than 0.1 gamma at the MAD sensor."

Page 23, Table 2, the following signal coefficients should be changed to read:

Component	North-South		East-West
	Roll	Pitch	Roll
TT			$\pm 0.349 \sin 2\phi$
LL		$\pm 0.175 \sin 2\phi$	
TV + VT	$0.349 \sin^2\phi$		
ll		$\pm 0.087 \sin 2\phi$	
vv			$\mp 0.172 \sin 2\phi$

Page 24, Table 4, Control Indicator (Unit 1) Servo Board 1A2 under column ASA-65/ASQ-10A P-3C should read: "51074 or 55551 (ECP 002)"

LOCKHEED CALIFORNIA COMPANY
PRODUCT SUPPORT – GOVERNMENT PROGRAMS
R. A. BARNARD, DIRECTOR

FLEET READINESS SUPPORT DIVISION H.A. Franck, Mgr.

P-3 Services	**G. E. Bentley, Mgr.**
S-3 Services	**W. R. Wilken, Mgr.**
Maintenance Planning	**F. Connell, Mgr.**

Navy Service Group – P-3	Fleet Support Group	Aircraft Modification Group	Navy Service Group – S-3
J. A. Hayes, Supvr.	M. J. Galli, Supvr.	F. B. Hays, Supvr.	R. B. Calvin, Supvr.

FIELD SERVICE OFFICES

MAJOR LOCATION	MAILING ADDRESS AND BUSINESS TELEPHONE	MAJOR LOCATION	MAILING ADDRESS AND BUSINESS TELEPHONE
NARF Alameda F. E. Weaver	P.O. Box 1363 Alameda, CA 94501 *(415) 521-2283*	NAS North Island A.V. Christophersen	NAS Box 5 San Diego, CA 92135 *(714) 435-8910*
NAS Barbers Point R. M. Keiser	P.O. Box 268 FPO San Francisco, CA 96611 *(808) 681-3444/682-3671*	NATC Patuxent River M. D. Garino	P.O. Box 218, NATC Patuxent River, MD 20670 *(301) 863-8186*
NAS Brunswick C. E. Phillips	P.O. Box 38 Brunswick, ME 04011 *(207) 729-000*	NAF Sigonella A. H. Parker	USNAF G-D Box 1032 FPO New York, NY 09523 *Sigonella 27-88-21, Ext. 359*
NAS Cecil Field W. H. Beydler	P.O. Box-162 NAS Cecil Field Jacksonville, FL 32215 *(904) 772-8517*	NADC Warminster J. N. Shovald	P.O. Box 220 Warminster, PA 18974 *(215) 672-9000, Ext. 2977*
NAS Jacksonville P.H. Tyree	P.O. Box 1300 Yukon. FL 32230 *(904) 772-3535*	Washington Navy Yard J. R. Mercer G.A. Seipp , NAVRES	Control Center, Bldg. 220, Washington Navy Yard, Washington, DC 20374 *(202) 433-4524*
NS Keflavik J. R. Everett	Box 16 U.S. Naval Station FPO New York, NY 09571 *Keflavik 2290*	Bonn, Germany G. C. Lauffenburger	Box 205 APO New York, NY 09080 *Bonn-Bad Godesberg 356621*
NAS Moffett Field J. Berezonsky	Unit One P.O. Moffett Field, CA 94035 *(415) 966-5461*	Teheran, Iran E. C. Joslen	P.O. Box 66-1516 Niavaran, Iran *Teheran 843940 or 848878*
NAS Norfolk A. W. Barber	P.O. Box 15148 U.S.Naval Base Norfolk, VA 23511 *(804) 423-8321*	Madrid, Spain F. E. Kiewert	USAF Section MAAG APO New York, NY 09285 *234-2800, Ext. 255 or 360* *(Air Ministry Madrid)*

LAGING HANDA

PATRON FORTY

LOCKHEED-CALIFORNIA COMPANY • A DIVISION OF LOCKHEED CORPORATION