# GAS TURBINE OPERATION IN EXTREME COLD CLIMATE

by

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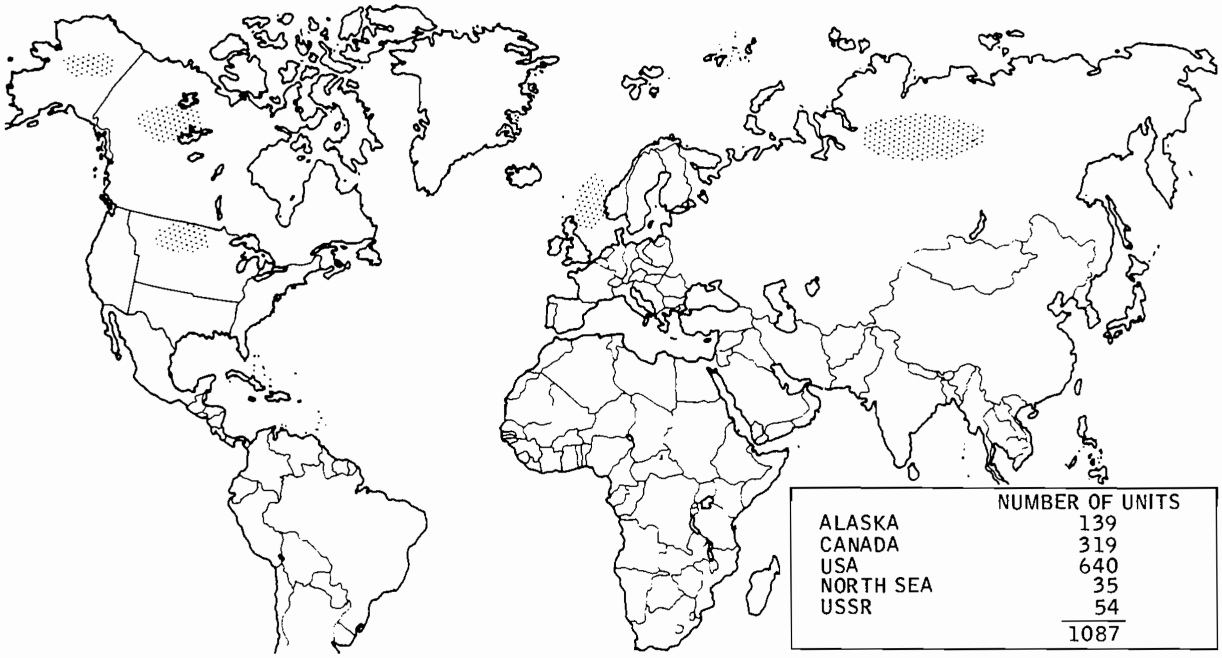
## ABSTRACT

The effects of extreme cold weather on gas turbine operation are described. Suggestions are made which will enhance overall operational effectiveness. The comments and specific recommendations are based on Solar's experience in the supply and maintenance of over a thousand Saturn and Centaur gas turbines in worldwide cold weather locations. Each manufacturer's gas turbine has its own tolerances and design constraints; each installation site its own peculiar climatic conditions; and each user his own operational requirements. A clear understanding by all parties involved of the requirements, conditions, and constraints will result in a dependable and economical installation.

## INTRODUCTION

The gas turbine's ability to operate reliably in the extreme cold of high altitude flight is taken for granted. However, the industrial gas turbine operating under extreme cold weather conditions is confronted by a completely different set of problems. Actually, the only factor in common between the aircraft turbine operation and the gas turbine operation is the extreme cold. When the environmental and operational conditions are recognized and effectively allowed for in design, application, and operation the inherent reliability of the basic gas turbine can be realized.

Operation in extreme cold weather normally represents only a portion of the industrial gas turbine's year round duty cycle. Thus any consideration of cold weather operation must be preceded by an evaluation of its operation under other weather conditions. Two factors must be considered; the environmental conditions at the installation site and the user's operational requirements, Figure 1.



| | NUMBER OF UNITS |
|---|---|
| ALASKA | 139 |
| CANADA | 319 |
| USA | 640 |
| NORTH SEA | 35 |
| USSR | 54 |
| | 1087 |

*Figure 1. Solar Gas Turbines in Cold Weather Service Around the World.*

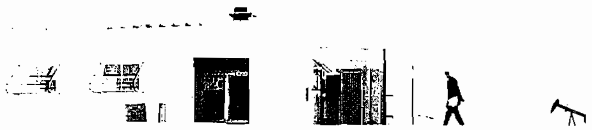


*Figure 2. Single Saturn Mechanical Drive Unit Used in Waterflooding. (Note Louvers Shielding Air Filter.)*

## USER REQUIREMENTS AND SPECIFICATIONS

The gas turbine operator's requirements, the manufacturer's standard, optional, and custom design features plus the specific site conditions must be clearly defined and understood by all parties to achieve the best possible performance and economy. Figure 2 shows an installation used in waterflooding, note the louvers shielding the air filter. Figure 3 shows an application on an offshore platform off the Alaskan coast. Figures 4 and 5 show the application of Gas Turbines as electric generators in Alaska. The above shows a variety of applications for the gas turbine in cold areas.

A specification defining the operational requirements for the site conditions as noted would be a useful tool. As a gas turbine manufacturer, we seldom see extreme cold weather operation described in any detail. All gas turbine manufacturers would appreciate the opportunity of working with gas turbine users to develop practical specifications.

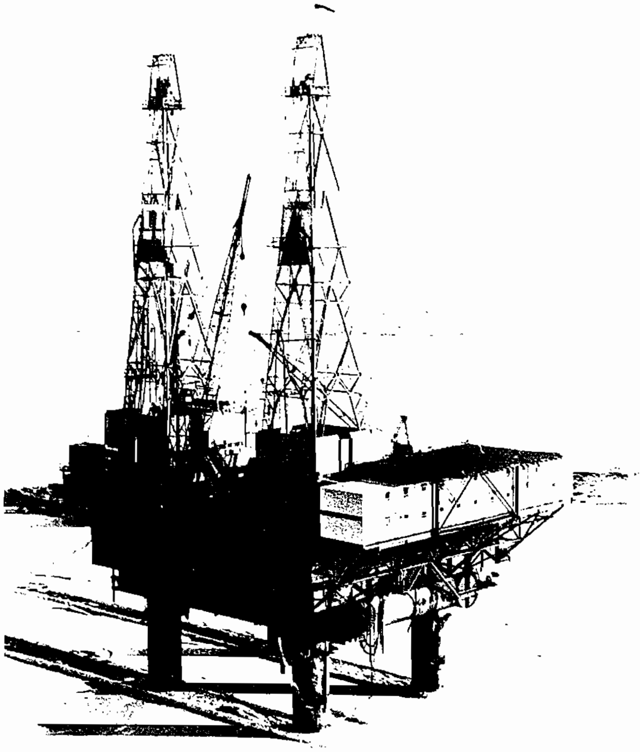


*Figure 3. Amoco Production Platform — Cook Inlet, Alaska.*

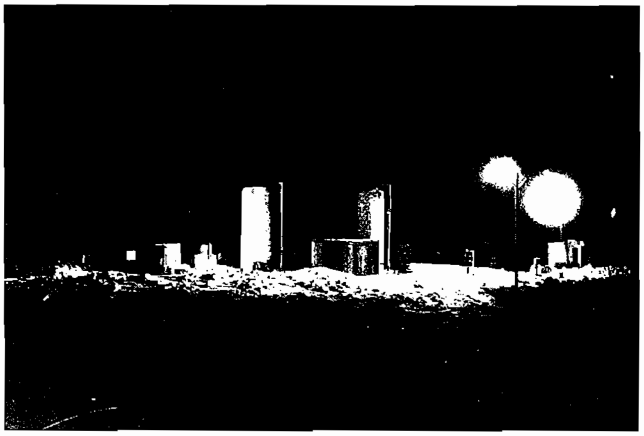


*Figure 4. Living Quarters and General Facilities for the Atlantic Richfield Base Camp on Prudhoe Bay are provided Electricity by Two 750 KW Saturn Generator Sets.*

*Figure 5. Point Barrow Naval Arctic Research Lab and the Towns of Barrow and Browerville are all Supplied Electricity by Saturn Mobile Generator Sets.*

A sample outline for such a specification as relates to extreme cold weather operation is shown in Table 1.

## COLD WEATHER CONDITIONS

The term "cold weather," as used in this paper, covers all climatic conditions occurring at temperatures below 3.3°C (38°F). This encompasses an extremely broad range of conditions: from comparatively mild to lung searing cold, from pouring rain to desert dry and from quiet calm to gale force winds. The cold weather climate can also include the air inlet system hazards found in warmer climates: erosive dust, corrosive salts, and fouling particulates. In addition, the summer respite from the cold is accompanied by swarms of insects in many areas.

Extreme cold may be taken as temperatures below -32°C (-25°F). Extreme cold presents some unique problems, but these are generally only an extension of the problems en-

1. OPERATIONAL REQUIREMENTS
    - 1.1 Essentiality (sole, last, redundant, effect of outage)
    - 1.2 Duty Cycle (emergency, intermittent, continuous)
    - 1.3 Location (remote, convenient)
    - 1.4 Controls (manual, automatic, local, remote)
2. SITE CONDITIONS
    - 2.1 Fuel
    - 2.2 Lubrication
    - 2.3 Installation (inside, outside, enclosed, unenclosed)
    - 2.4 Temperature Range (ambient, interior)
    - 2.5 Humidity (snow, rain, fog, sea salt)
    - 2.6 Winds (direction, velocity, duration)
    - 2.7 Airborne Contaminants (dust, insects, exhausts)
    - 2.8 Orientation of Air Intake (sketch)
3. SOUND LEVEL LIMIT
4. TRANSPORTABILITY LIMITS
    - 4.1 Weight
    - 4.2 Dimensions
5. SPECIAL GAS TURBINE REQUIREMENTS
    - 5.1 Ventilation
    - 5.2 Starting
    - 5.3 Others
6. SPECIAL DRIVEN EQUIPMENT REQUIREMENTS
7. SPECIAL COLD WEATHER REQUIREMENTS

*Table 1. Sample Outline of Specification for Gas Turbine Set*

countered in any cold operation. Because the temperature must drop to, or warm up from, an extreme cold condition, the transition weather must be considered, too. As a practical matter, the transition weather tends to cause more problems. More equipment is exposed to it, and generally fewer precautions are taken because the operating problems are either not recognized or glossed over.

All cold weather operation encounters ice or icing in some form. It principally affects the air inlet system of the turbine, but also its fuel supply, ventilation and pneumatic controls as well as exposed movable parts such as actuators, louvers, and doors.

## PRECIPITATE ICING

Precipitate icing includes all forms of free water (as either a liquid or a solid) which would be drawn into a gas turbine air intake during operation in a cold atmosphere. These include:

*Hail* — A sphere or "lump" of clear ice or alternate layers of clear ice and an opaque snowlike structure ranging in diameter from 5 to 50 mm (0.2 to 2.0 inches).

*Snow* — A hexagonal patterned ice crystal which grows while falling or floating through the atmosphere. Its whiteness is due to its open structure and entrapped air.

Snow long on the ground in low humidity areas and subject to wind movement becomes dense, rounded, and hard or gritty. Snow can only become clear ice by melting and refreezing, but it can become quite solid and dense by compaction.

*Sleet* — A mixture of rain and melting snow.

*Freezing Rain* — A rain containing supercooled water droplets which, upon contacting a cold surface, form clear ice.

*Ice Fog* — A fog consisting of suspended ice crystals at temperatures of -34.4°C. (-30°F.) and below. (Only small quantities of water vapor are necessary to achieve saturation at these low temperatures.)

*Mixed Fog* — A fog consisting of suspended ice crystals and supercooled water droplets in an ambient temperature range of -19°C to -40°C. (-22°F to -40°F).

*Water Fog* — (super-cooled fog) a fog (or mist) consisting of super-cooled water droplets at an ambient temperature range of -19°C to 3°C (-22°F to 38°F).

*Hoar Frost* — A build-up of ice crystals on a cold surface formed by the supercooled water droplets from a water fog. It is also called "frozen dew" or "rime."

*Fog* — (nonsupercooled) A fog (or mist) consisting of water droplets whose temperature is above 0°C (32°F).

*Ice* — The solid state of water. Ice is normally colorless, hard, dense and brittle. The more air entrapped during freezing, the more opaque ice becomes and the less dense.

*Rain* — A liquid form of water with nonsupercooled droplets.

Precipitate icing can occur by an accumulation of solids (snow, ice fog, hoar frost) on an exposed surface. Or it can form by the freezing of liquid water (rain, water-fog) progressively built up in layers.

## CONDENSATE ICING

Condensate icing occurs when air saturated with water vapor (but containing no free water, liquid or ice) is accelerated. The subsequent drop in pressure and static temperature causes condensation. The water droplets thus formed will supercool and freeze into ice crystals. "Condensate icing (as it is formed on gas turbine inlet structure) does not exist as an atmospheric condition per se, but is a situation induced by the engine under a certain atmospheric condition." (Ref. 5, page 8). ("The classification of hoar frost as precipitate rather than condensate icing may be questioned." (Ref. 5, page 8). For this paper "condensate icing" is considered a turbine-induced condition and hoar frost a natural condition).

## CONDENSATION

When water vapor in air is cooled to or below its dew point, condensation occurs and water droplets begin to form. These submicron droplets grow in size by agglomeration. At about one micron in size, these droplets begin to settle slowly in still air. At 2 to 50 microns in size, a fog is formed; at 50 to 100 microns in size a mist; and at over 100 microns in size, first a drizzle, then a rain results.

As a practical matter, the saturation pressure of water at a curved surface is greater than over a plane surface for which the dew point is conventionally defined. This would indicate droplet formation well below the dew point, but in fact condensation and droplet formation depend upon "condensation nuclei." The larger of these condensation nuclei are sea salt and dust particulate. The smaller are mainly the particulate products of combustion. These nuclei promote the formation of droplets at or just below the dew point.

## FREEZING

Water droplets on cooling do not normally freeze exactly at 0°C (32°F). They will supercool, and depending on the presence of a "freezing nuclei" or contact with an ice particle or a cold surface, freeze at some lower temperature. Freezing nuclei, like condensation nuclei, are micron or submicron sized particles of dust, salt, exhaust particulate, or ice crystals. They promote ice crystal formation. The larger the water droplet, the more likely it will contain a freezing nuclei, and the less the degree of supercooling required to cause it to freeze. Because of this action, the gas turbine may be exposed to an ice or mixed fog of its own making or resulting from adjacent combustion exhausts.

## SPECIFIC PROBLEM AREAS AND SUGGESTED SOLUTIONS

Our experience at Solar and reports from our customers indicate four principal problem areas in extreme cold weather operations:

- Air handling — combustion & ventilation
- Lubricating oil systems
- Fuel handling systems
- Materials and construction

In resolving specific problems in these areas, there are few absolutes. Operators tend to use methods and equipment which work for them. They may have gone through a number of costly iterations to arrive at a workable solution. "Some of these approaches are far from foolproof and work only because the operators are fully prepared to devote the effort necessary to make them work." (Ref. 8, page 6). But one operator's solution may not be at all suitable for someone else in what at first glance appears to be a similar situation. The comments offered here are suggested solutions. They represent what experience indicates is most likely to work for a typical application of Solar's gas turbines. The comments do provide points to consider for any gas turbine or installation.

## INLET AIR HANDLING

The cold weather condition which most directly affects the gas turbine, and more particularly its combustion air compressor, is ice ingestion.

### *Problem:*

*Foreign Object Damage/Ice Ingestion*

The gas turbine operates at comparatively high rotational speeds. Its initial compressor stages have long blades, unsupported at the tip, and are of a thin airfoil cross section for optimum aerodynamic efficiency. These blades are subject to foreign object damage. They are protected by an inlet screen in most industrial gas turbines. An object small enough to pass through this screen may dent, or "ding", the compressor blades but will not break or severely damage them. When the total quantity of such ingested foreign objects is very small, and their occurrence is infrequent, turbine operation to a normal disassembly inspection interval, with only minor repair at overhaul, is typical. Larger quantities, frequently ingested, will deform the compressor blades and vanes eventually causing an irrecoverable loss of compressor performance. (The usual first sign of damage is a peculiar inlet noise tone.)

Ice must be considered as a "foreign object". Rather than denting or "dinging" a moving blade, the ice will shatter upon impact. However, if its mass is sufficient, it will bend or break the blade upon impact causing extensive damage. The effect on the turbine can be identical to ingesting a large loose nut or bolt. Ice ingestion can severely damage the compressor, requiring its immediate removal from service for a major repair. A factory cost comparison for the complete reblading of a compressor versus the repair of a few blades and vanes is on the order of four to one. Gas turbines will vary in their ability to sustain ice ingestion without damage. The manufacturer should be consulted in this regard. Ice buildup is generally cumulative. If no preventive action is taken, it appears only a question of time until a chunk large enough to do real damage to any gas turbine will result. With a well designed protective compressor inlet screen, properly installed, there is only one way for chunks of ice sufficiently large to cause this kind of damage to enter the compressor. The ice must form INSIDE the inlet screen surrounding the inlet air housing of the compressor. The size of the ice chunk capable of causing damage depends upon its density, where it strikes the moving blade, and the speed and impact angle at which the blade is struck, plus the capability of the blade to sustain the impact without damage. For practical purposes, there is no way to assure the formation of only small, soft nondamaging ice chunks, and so the formation of any ice in the compressor throat, inside the screen, must be prevented.

As the intake air passes through the inlet screen into the inlet housing, it is accelerated and its static pressure and dew point decrease. The dew point of water temperature is reached at the inlet guide vane surfaces at an ambient air temperature of 3.3°C (38°F) for Solar's Centaur gas turbine and at a slightly lower temperature for the Saturn gas turbine. This would appear a representative value for most gas turbines. Water vapor will condense out of the air and form "condensate icing" at or below this temperature. This condensate icing forms an aerated soft rime or frost on a relatively small area of the inlet guide vanes. It is considered unlikely that a large enough volume of ice, compacted to a sufficient density to cause damage upon ingestion could be formed in either Solar's Saturn or Centaur gas turbines. This is also believed to be true of most other manufacturer's turbines as well, but each turbine's sensitivity varies, and the manufacturer should be questioned about "condensate icing" on each specific model.

Free water can enter the turbine inlet air system as dry snow, or ice crystals, and be ingested in reasonably large quantities without difficulty as long as no melting and refreezing occurs, and the quantity involved does not obstruct the inlet screen.

Free water as a liquid can be ingested as a fine mist at temperatures above 3.3°C (38°F) without causing damage. (As a matter of practicality, any mineral salts dissolved in the water droplets will deposit in the compressor and foul it.)

Because the conditions under which free water, either liquid or solid, might be safely ingested are so limited, a much better approach for cold weather operation is to try to prevent the entry of free water entirely. Under cold ambient temperature conditions ice crystals or snow can melt on the bottom of ducting inside a warm turbine compartment. This melted ice or snow and free water entering as a liquid or liquid droplets,

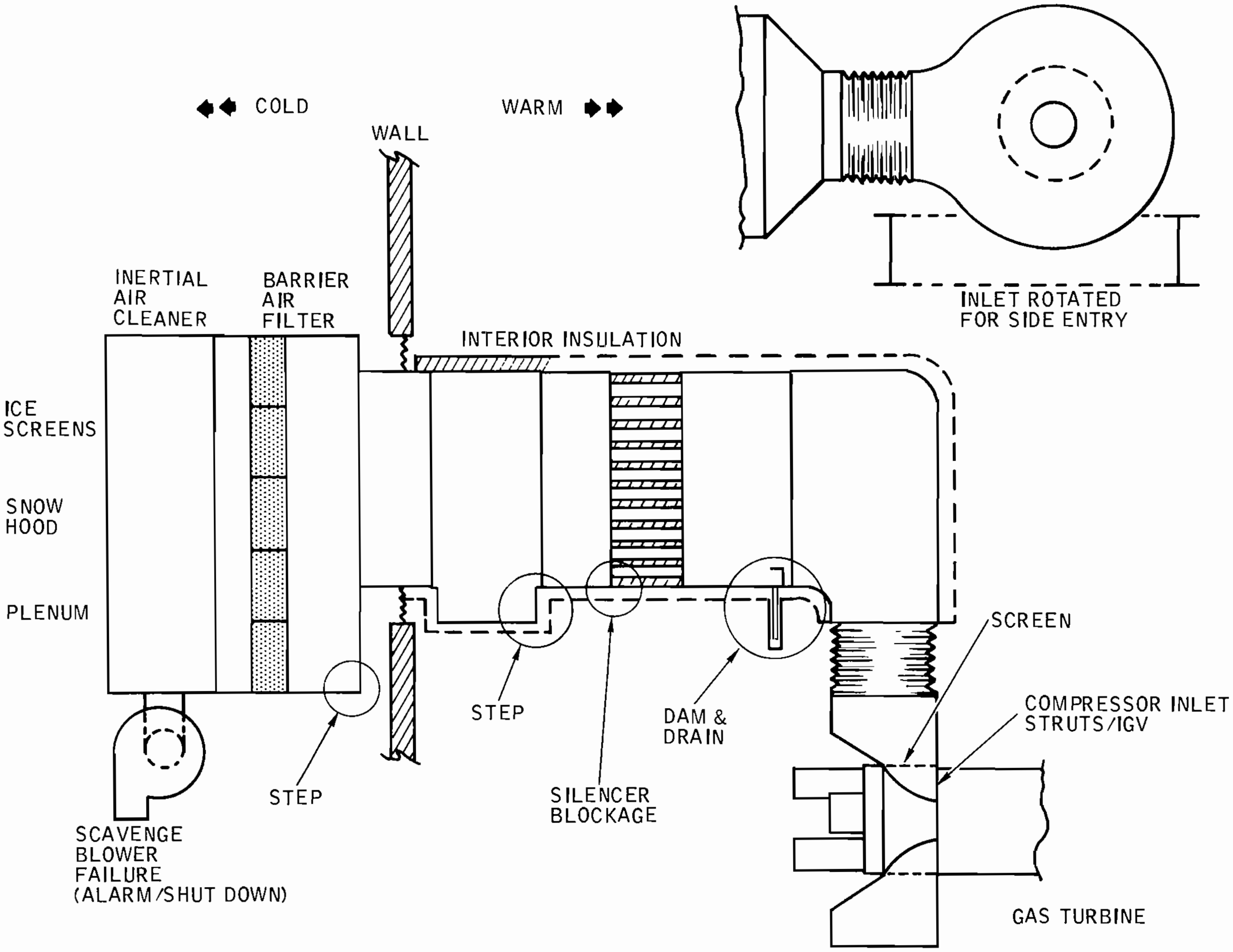


*Figure 6. Typical Inlet System for Centaur Gas Turbine.*

can be carried along the ducting into the compressor intake, through the protective screen and then refreeze. The formation of precipitate icing in any significant amount in this location, on the inside of the inlet screen, on intake struts, bellmouth, nose cone, or inlet guide vanes, is going to cause extensive damage.

*Comment*

The design and construction of a gas turbine inlet air system for operation in cold ambient temperatures should contain features which will prevent liquid free water from entering the compressor inlet housing or inlet bellmouth screen and minimize the entry of either solid or liquid free water into the inlet ducting, the air cleaner/filter, and the air intake opening.

A typical inlet system for a Solar Centaur gas turbine is shown in Figure 6. Suggestions for water entry prevention are indicated.

- The inlet muff may be rotated for a side entry. Water is much less apt to be drawn over and up into the inlet screen, as opposed to falling straight down from the duct elbow as shown in the side elevation.
- An inlet silencer, a step transition, or a dam or wier with a trapped drain, should be installed to prevent migration of water along the bottom of a horizontal run of ducting.
- Ducting in a warm compartment should be insulated to avoid melting dry snow which could enter during operation or during shut down periods.
- Air filter media can be used as a water barrier. (It will freeze up of course, but this, at least, transfers the problem away from the turbine inlet.)
- An inertial air cleaner has good water and snow removal characteristics. It may be used alone or in combination with other components to exclude most types of free water. However, it is also liable to obstruction by icing under wet snow, sleet, ice fog, hoar frost, and freezing rain conditions.
- Ice screens, large plenums, and weather hoods can reduce the intake velocity and thus the amount of free water presented to the air intake. This will extend the time required to obstruct the inlet air cleaner or filter.

*Problem:*

*Air Intake Obstruction*

The prevention of free water entry into the air inlet system, and thus into the turbine's compressor inlet, is comparatively straightforward. How to assure that the free water, thus prevented from entering, does not obstruct and eventually seal off the air intake is a much more complex problem.

The first component, or an air filter, in the inlet air system is usually subject to the greatest degree of precipitate icing obstruction. The intake components should be designed, selected, and arranged to:

- Minimize ice formation, and
- Enable it to be manually removed, or
- Provide for automatic removal (de-icing), or
- Provide for automatic prevention (anti-icing).

It is important to note that blow-in doors (implosion doors), if fitted, are intended only to protect against the possible collapse of inlet ducting, and allow for either the removal of the intake obstruction or the orderly shutdown of the turbine. It should not be the intent to continue turbine operation while drawing inlet air through a blow-in door. The inlet components provided to protect the turbine are thus bypassed and there is a real risk that the conditions which caused their obstruction will cause considerable damage to the turbine by allowing the entry of free water and the formation of ice inside the inlet screen.

*Comment*

An appraisal of the specific on-site icing conditions, coupled with a year-round weather and air quality review should be made. Inlet components should be added to the system to accomplish specific ends. Then the whole system should be reassessed for performance, cost, transportability, ease of construction, maintenance, and compatibility with other adjacent structures and the site plan.

Beginning at the compressor, the ducting interior should contain no projections, ladders, stays, wiring, or other appurtenances which could accumulate snow or ice. The inlet silencer will be the only exception. For acoustic purposes the silencer will normally be installed as close to the inlet as possible. But for cold weather, it is suggested that some distance, one change in the direction of the inlet air flow after the silencer, and a low velocity plenum be used after the silencer if possible.

If the duct work and silencer are kept at ambient temperature, then the possibility of melting, migration, and refreezing is minimized. When a run of ducting is to be made in a heated building, it should be thermally insulated. The inlet muff or plenum should also be thermally insulated if there is a significant warm melting surface exposed.

The air filter/cleaner must be selected based on the assessment of the on-site airborne particulate contamination. If the efficiency of an air filter is indicated, then a summer/winter operation cycle should be considered. The filter media would be used in warmer weather and removed in cold weather. An inertial air cleaner may be used alone or as a pre-cleaner for an air filter.

An air filter will trap snow and ice fog crystals as it will any other airborne particulate. Moisture can freeze in the media. An air filter will require upstream protection in every instance.

By using an inertial air cleaner ahead of the filter, most of the free water, either liquid or solid, can be removed from the air stream. In many cases this may be sufficient protection for an air filter. Under some conditions, the air cleaner may pass too great an amount of ice fog crystals or very fine snow to avoid filter obstruction and either the filter media will have to be removed or other measures taken. An inertial air cleaner of either the vane or tubular type depends upon a scavenge blower to remove separated particulate. It is essential that this blower function. The efficiency of a scavenged inertial air cleaner is seriously compromised when the blower is not operable. There is a marked tendency of the vane type to plug the bleed slot with wet snow, ice or slush, and of the tubular type to reverse flow. When this occurs, the particle separation efficiency drops to virtually zero. For this reason, a "blower failure" switch should be used to alarm and/or shut down the turbine.

Both the vanes and tubular swirlers used inertial air cleaners can accumulate enough ice, frost, or snow buildup to obstruct the air flow. By using an ice screen ahead of the air cleaner, the accumulation of ice will form on the screen where it can readily be removed. (An obstructing ice buildup inside an inertial air cleaner can only be removed by melting it off.)

Ice screens and weather hoods should be used in combination. They can extend the time it takes to obstruct the intake. This additional time may be enough when the climatic conditions causing icing are transient and sufficiently short in duration. In an attended operation it may be practical to manually remove obstructing snow, frost, or ice from the screen. When persistent conditions, unattended sites, and essential service operation are involved, anti-ice heating will probably be required. The larger the ice-screened area, the longer will be the accumulation time to obstruct. The size of the hood will have to be a compromise of the many factors involved for a specific application. It should be noted that the intent of the screen is to provide a surface, outside the air cleaner or air filter, on which icing can take place. Typically 12.5 x 12.5 mm (1/2 inch) mesh wire is used. By locating the screens so that they are 45 degrees to the direction of air flow, more moisture will be removed. The use of corrugated perforated sheet stock or expanded metal screening serves the same purpose. A provision should be made to replace the ice screens with (or add) insect screens for summer operation. The air flow must be up into a weather hood, and the larger the intake area, the lower will be the particle (snowflake, ice crystal, or water droplet) carrying velocity. An entering velocity of 3 m/sec (600 fpm) is used for small hoods. These are generally suitable for wet snow, sleet, and rain. A value of 1 m/sec (200 fpm) is suitable for most falling snow and water droplets above about 100 microns in size.

Air intake heating offers the only sure way of avoiding the eventual obstruction of the air inlet system components when some types of icing conditions persist. This heating may be considered as "anti-icing" when the deposition of any appreciable amount of ice is prevented, or as "de-icing" when a tolerable ice buildup is periodically melted off. Anti-icing may either involve heating the intake air to a temperature greater than 3.3°C (38°F) (total) or heating it to a temperature sufficient to reduce its relative humidity to less than 60 percent (partial). The maximum inlet temperature rise required is about 11°C (20°F) and typically 5°C (10°F) would be sufficient.

When exhaust gas, containing some 3 percent moisture is directly injected, additional heat must be added to compensate. The intent of partial rather than total heating is to effectively reduce the intake air relative humidity to about 60 percent. Under this condition ice crystals will not form from supercooled water droplets (hoar frost) and ice crystals already present (ice fog) will tend to evaporate.

De-icing will result in loose ice and melt being carried downstream. It will refreeze if not removed. The inertial air cleaner offers the best means of removal, but the "on" heating cycle must be sufficiently long to insure all liquid water has cleared the air cleaner. The control of the system would sense a buildup of ice by an increased differential pressure and initiate the heating "on" cycle. Sufficient heating (total) to melt the ice (higher than 3.3°C (38°F)) is required. When the differential pressure returns to normal, the heating is turned "off" after allowing sufficient time to clear all liquid water. Air intake heating schemes include:

1. Exhaust gas reingestion — to above freezing (total)
2. Exhaust gas reingestion — to 60% R.H. (partial)
3. Combustion heater (separately fired) — as required (total or partial)
4. Compressor bleed — to 60% R. H. (partial)
5. Heat exchanger — to above freezing (total)
6. Heat exchanger — to 60% R. H. (partial)

The exhaust of the gas turbine provides a large source of heat. It contains sufficient oxygen (15 to 18 percent) to be used as a combustion air supply. It also contains 3 percent water vapor. Additional heat is required to compensate for the increase in the moisture content of the air/exhaust mixture. The exhaust contains fouling particulate and contaminants, more in liquid fueled turbines and less in gas fueled. An increase in fouling and thus maintenance will result in the turbine's compressor or in an inlet air filter. The magnitude of the increased maintenance depends upon the combustion characteristics of the turbine and the amount of heating time required. The use of a barrier filter might be considered to avoid compressor fouling. Even uniform heating through the entire intake cross sectional area is essential. Water migrating into cold spots will refreeze and cause problems.

For separately fired combustion ingestion, the same criterion applies. The obvious disadvantage is that significant additional fuel consumption is required. Also, operation in a hazardous environment would not be permitted. These two serious drawbacks generally rule out its use, except in special cases where extensive alterations would be necessary to duct turbine exhaust gas to the intake.

Compressor bleed air heating has been used by other manufacturers on a number of turbines. When there is available a supply of hot bleed air normally used for cooling purposes and then vented, this provides an ideal supply of clean dry air for intake heating. Typically about 1.25 percent of the turbine mass flow is available and will raise the inlet air about 3.64°C (6.75°F) and result in a 30 percent reduction in relative humidity. For a turbine without this feature (i.e.: not having vented bleed cooling air) the use of compressor bleed would represent about a 7 percent power loss and a 3.5 percent increase in specific fuel consumption. Because the available pressure is high, the required ducting and manifolds are small as compared to those for exhaust gas. As with the exhaust gas a uniform, even distribution across the intake opening is required.

Heat exchangers using either exhaust gas or separately fired heaters avoid the problems associated with direct exhaust ingestion: added moisture and fouling particulate. The separately fired heater exchanger problems of hazard and fuel consumption still apply.

There is now available an exhaust gas heat exchanger which appears to have excellent potential. It provides a double row of hollow, heated louvers. The shape and arrangement of the louvers act to remove moisture and thus avoid the reentrainment of melted ice or water. A variable flow exhaust gas pickup provides for 3 to 12 percent of the turbine exhaust to be led through the louvered panels installed inside weather hoods and in front of the air intake. Figure 7 illustrates the computer predicted performance of a typical panel. Field tests have confirmed, in actual usage, the predicted temperature rises. A typical layout of components making up the system is shown as Figure 8. In comparing inlet heating schemes it should be noted that:

Total heating to above freezing will

- Melt existing ice
- Prevent ice formation
- Cause a loss in power in proportion to the actual inlet temperature versus the ambient temperature

Partial heating to a temperature rise will:

- Prevent precipitation icing from supercooled water droplets (hoar frost)
- Prevent condensate icing
- Cause a loss in power in relation to the actual inlet temperature versus the ambient temperature

Partial heating to a temperature rise with heated louvers will, in addition to the above:

- Prevent precipitation icing from spray, rain, sleet, snow (under most conditions),
- Reduce precipitation icing from ice fog and white out.

In review, it may be stated that total heating to above freezing will provide complete protection in a well designed system at the sacrifice of considerable power. Partial heating to a temperature rise sufficient to reduce the relative humidity to about 60 percent will prevent condensation icing, and reduce the tendency of some types of precipitate icing to form. The use of heated louvers further reduces or eliminates most forms of precipitate icing. Partial heating at temperatures a little below freezing will effectively be total heating and eliminate all kinds of icing in this area.

In extreme cold climates the two forms of precipitate icing not encountered elsewhere are ice fog and white outs. Both involve crystals of ice and solid rounded snow; ice fog in sizes from 2 to 30 microns, and the snow from 10 to 200 microns. These crystals and particles can safely be ingested at the compressor inlet if they are not allowed to melt and refreeze or accumulate to the point of obstruction anywhere in the inlet system. They can to a large extent be scavenged out of the air stream by an inertial air cleaner, or settled out by a very large up draft plenum. (This plenum must have snow removal access or a heated floor and drain.)

In reviewing the component cost of various heating systems, four elements are involved:

- Distribution manifold or heating louvers
- Insulated ducting
- Exhaust gas pickup or bleed valve
- Control system

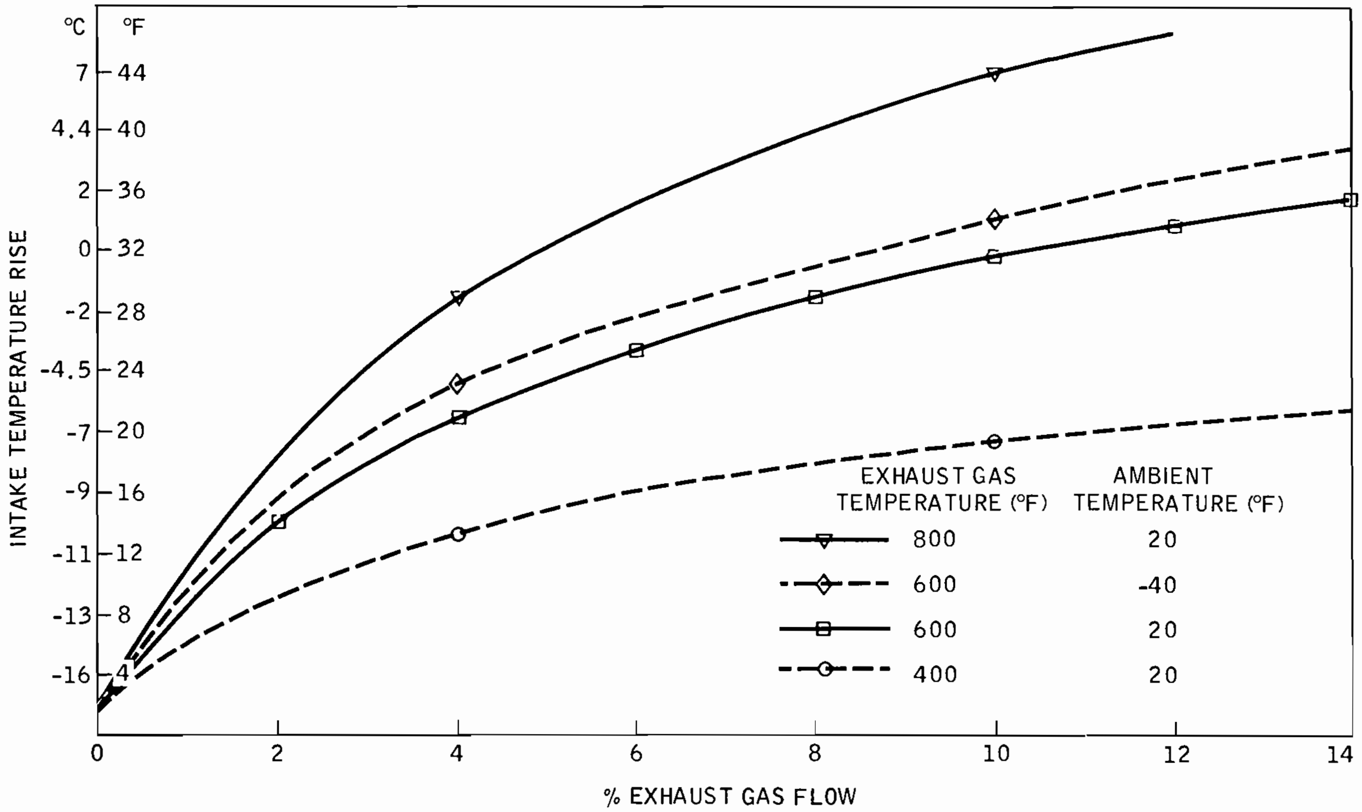


*Figure 7. Computer Predicted Performance Heated Louver Panel.*

The exhaust gas ingestion manifold will be less expensive than heated louvers, but not much. The differential will be even less if the exhaust gas ingestion manifold (piccolo pipes) are a custom design and the heated louvers are a standard product available in standard sized panels. The ducting cost will depend more on its length and the number of elbows, rather than its diameter. Bleed air ducting will be somewhat less expensive because of its very small diameter, but because it will operate at a higher pressure and lower temperature, it will require more expensive joints and insulation. The exhaust gas pickup, or bleed valve, or induced draft blower (if one is required) will all be about equal in price. The control required will be essentially identical for each system. Its cost and complexity are dependent upon the degree of modulated automatic control and sensitivity of the sensor required. A total estimated system acquisition cost ranges from $4.00 to $1.00 per horsepower for gas turbine ranging in size from 1,000 to 10,000 horsepower. Each installation must be considered individually, but total heating to above freezing will also cost in horsepower lost and in extreme cold will require additional cost for larger capacity and the thermal insulation of the inlet system.

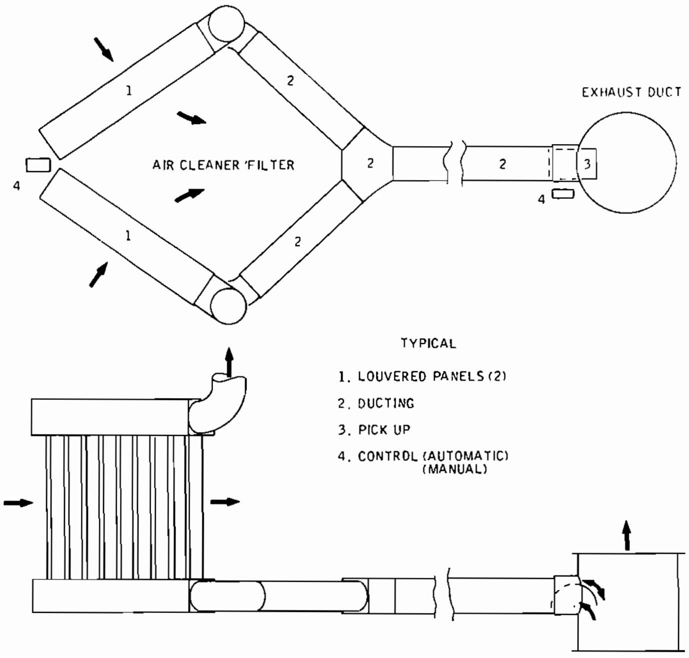


*Figure 8. Exhaust Gas Heat Exchanger.*

Each installation varies of course, but our experience leads us to favor an ice screen protected, low velocity approach, or the use of partial heating with hollow moisture removing louvers. These two approaches when used individually with other system components suited to the site and operational conditions will provide the best overall performance.

## VENTILATION AIR SYSTEMS

Many of the same criteria for inlet air systems also apply to the ventilation air supply. The problems encountered are more in the nature of serious inconveniences, rather than a curtailment of operation or possible damage.

*Problem:*

If full ventilation is used in extreme cold, all the equipment involved will be exposed to very low ambient temperatures.

Localized heating will certainly be necessary from some systems or equipment, and may be necessary for others. Removal of snow, ice and water from the ventilation air will be necessary. Fire detection and extinguishing systems will still have to function and protect the equipment. Maintenance or servicing will have to be accomplished.

If recirculation is used and only enough ambient ventilation air is supplied to a thermally insulated compartment or module to prevent an excessive heat rise, then the equipment can operate in a "normal" ambient condition. Accurate thermostatic control of the supply will be required. Provision must be made for adequate ventilation when the ambient temperature warms up to summer highs.

*Comments:*

Consider first a "cold soak" condition with the unit not operating and determine what components will require heating and to what level to be able to start the unit.

During operation determine which components will continue to require heating, and how much radiated heat is available from the turbine, oil system and driven equipment. What spaces will be occupied by operating personnel? Generally batteries, battery charger switchgear, control valves, and lube oil tanks will require localized heating.

Oil or liquid pressure switch sensing lines, full of semi-congealed fluid at low temperature, will act as a time delay. The sequencing of operations will be altered by the temperature and the lengths of the lines involved. This must be allowed for in the design of any control system.

When operating, cold ambient air will be flowing through the inlet ducting. This ducting, or any intake plenum abutting a heated space, should be insulated.

Figure 9 illustrates an insulated enclosure used for a standby generator set. Some 75 kw is required to maintain the interior at 4.4°C (40°F) when the ambient is -56.0°C (-70°F).

## LUBE OIL

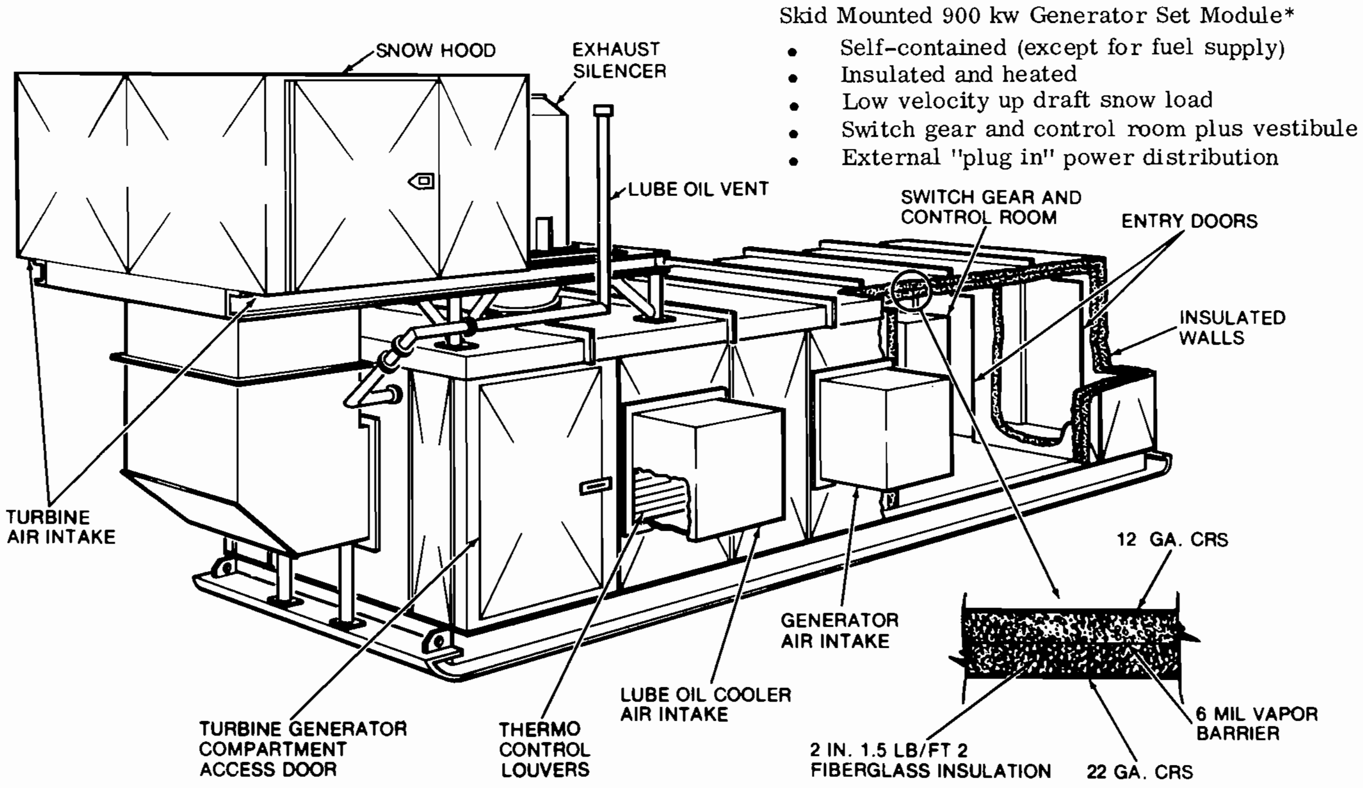
Each gas turbine manufacturer will have to comment on the cold weather lube oil requirements of a specific unit. It is assumed a suitable oil has been called out and will be used.

*Problem:*

There are three general problems which apply in the area of gas turbine lubrication. These are cold oil, excessive heat loss (too low an oil temperature) and oil cooler operation.

*Comments:*

Even despite the selection of a wide range oil, it is probable that during a down period the oil will cold soak to a temperature sufficient to render it virtually unusuable. Oil tank heating is



Skid Mounted 900 kw Generator Set Module*

- Self-contained (except for fuel supply)
- Insulated and heated
- Low velocity up draft snow load
- Switch gear and control room plus vestibule
- External "plug in" power distribution

*The Alyeska Pipeline Service Co. has ordered 10 Solar 900-kilowatt generator sets to be used in case of a power failure at construction camps along the 800-mile Alaska pipeline. The specially designed modules are insulated so that the control room will be 40 degrees F. when the outside temperature is 75 degrees below zero.

*Figure 9. Features of 900 KW Generator Set Module.*

required typically to maintain the bulk of the oil at a temperature at least 5.5°C (10°F) over its pour point. If the oil lines, and the oil passages in the turbine are at a low ambient, then a period of pre-lubing, or circulation of oil through the turbine, is required. This period should be long enough to assure a supply of the proper viscosity oil to all the bearings. A further difficulty may arise from the proportion of cold passages to the amount of oil being circulated. It is possible that an oversize heater will be required to compensate for the heat loss. This problem is accentuated in gas compressor sets in the area of the driven compressor seal oil system. At one location, for example, gas is purged through the compressor before start up. The compartment temperature and the gas compressor is at 16°C (60°F) prior to start up. As the purged gas is expanded through the stationary compressor it drops in temperature from -3.3° C (26°F) to -40°C (-40°F) and chills the compressor. The lube oil system (and the compressor) design must allow for this condition.

The oil cooler must be sized for full load operation at the highest summer ambient. This may be well over 25.5°C (80°F), and in some locations 72.2°C (100°F). It will tend to overcool in cold ambient temperatures. The turbine manufacturer will recommend a suitable oil and/or air bypass, thermostatically controlled. Care must be taken in the system design, so that when the oil temperature rises to the normal operating level, a provision is made to prevent a sudden oil by-pass shut-off and an unrelieved pressure increase, while congealed oil is slowly being squeezed out of the oil cooler. Recirculating the oil cooler air supply has caused high oil temperature shutdowns in many installations. Mounting the oil cooler in the module or building wall to avoid this can make the interior intolerable with a blast of sub-zero air dumping into the space. Even when the turbine is shut down, the cold wind blows through the cooler like an open window. To avoid this, louvers are often installed and then problems with leakage or binding arise. For these reasons many installations have the oil cooler remote mounted, horizontally, outside the building. In cold winter or hot summer, oil temperature changes will result unless attention is paid to a good modulating oil temperature control system and the particular installations operating conditions.

## FUEL

An uninterrupted supply of clean moisture free fuel at a suitable pressure and temperature is essential for reliable gas turbine operation.

*Problem:*

Natural and associated gas fuels are available and inexpensive at the well head or oil separator of producing Arctic fields. This is a preferred turbine fuel. We currently have at least three installations where the fuel gas temperature is -40°C (-40°F). It is anticipated that fuel gas temperatures as low as -50°C (-60°F) may be encountered due to the low ambient and the expansion of the gas from a high initial pressure to the normal fuel supply pressure.

*Comments:*

The extremely volatile hydrate formed at these temperatures appears to attack and swell the low temperature seals in valves and other fuel system components causing leaks and failure to shut off. This hazard must be considered in the selection of gas fuel system components. A companion hazard is the differential contractions which take place when the cold fuel gas flows through the warm fuel system components at start up.

(We have not had problems with gas driven starters or pump motors, but these too should be carefully selected.)

Moisture must be excluded from the fuel either liquid or gas to avoid ice blockage.

Dual fuel (liquid and gas) capability is an advantage in smaller gas turbines which may be relocated, or where the fuel supply is unreliable or subject to possible change in the future.

## MATERIAL

The correction of problems and modifications found necessary, as a result of the severe cold weather operation, is extremely difficult and costly to make at remote Arctic sites. Every reasonable effort should be made to test all of the equipment in the arrangement or configuration which will be used in the actual installation. To "wave it in place" on the job site may prove a very costly expedient. The parts costs are insignificant. Transportation first and labor second are the big costs, plus the cost of extended down time (Figure 10).

*Problem*

Differential expansion (contraction).

*Comments:*

Parts which match nicely in the summer in California may not fit at all at -40°C (-40°F). Parts or piping attached to outside walls are a particular concern. The whole design; turbine, driven equipment accessories and the entire installation, must be carefully reviewed for the effect of differential thermal expansion. The drafting of cold air through a shut down turbine in a warm room, a blast of air through an open door chilling one side of a warm turbine thus misaligning it, and cold gas purging are just three examples of high differential temperature conditions.

*Problem:*

Electrical system malfunctions.

*Comments:*

Our experience indicates solid state electronic components may malfunction when cold soaked at low ambients. We tend toward the use of strip heaters in critical electrical areas. Their use also avoids the formation of moisture inside explosion-proof control boxes and on switchgear.

*Problem:*

Service access and working conditions.

*Comment:*

Exterior walls or connections, doors, latches, switches, buttons, fittings, valves, and other equipment exposed to or installed in a cold ambient location must be designed so that personnel wearing insulated gloves (about as clumsy as a catcher's mitt) can operate or work on them (Ref. 7). Because of the twenty-four hour winter darkness, ample lighting must be provided. Sufficient room for personnel wearing bulky outer winter clothing and insulated boots to move around equipment must be provided. Enclosed modules should have a vestibule with space to stow cold weather outer clothing. Care should be taken with the design of equipment which must be moved, opened, lifted, or actuated when extremely low temperatures

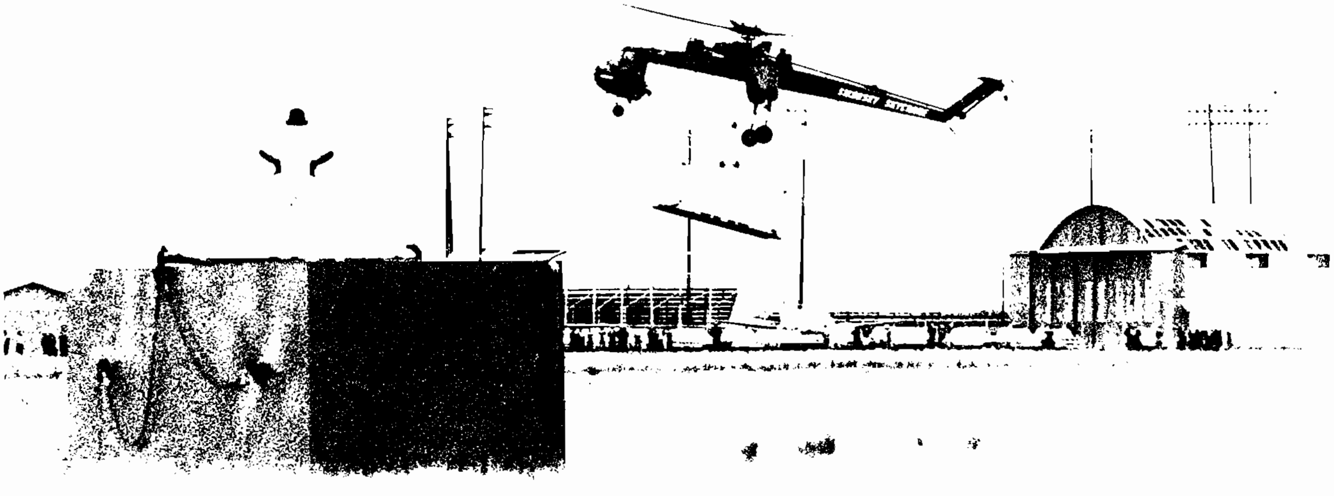


*Figure 10. Saturn Generaotr Module Used in Air Transportable Drilling Rig Being Air Lifted.*

embrittle hinges, lifting eyes, lines, doors, louvers, flanges, brackets, etc. Differential contraction, notch sensitivity and abnormal stress should be avoided.

## CONCLUSIONS

The inherent ability of the gas turbine to continue reliably in service during severe cold weather conditions is often the principal reason for its selection.

The proper design and configuration of the gas turbine and its supportive accessory equipment, taking into consideration both equipment limitations and the installations particular requirements, can enhance this ability.

A good understanding of both general climatic and specific site conditions by all parties involved is essential. The effort to provide for extreme cold weather operation should not compromise reliable performance during the rest of the gas turbine operation.

Close user-supplier cooperation from the beginning of a program or job will promote a better, more reliable installation at a lower overall cost.

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