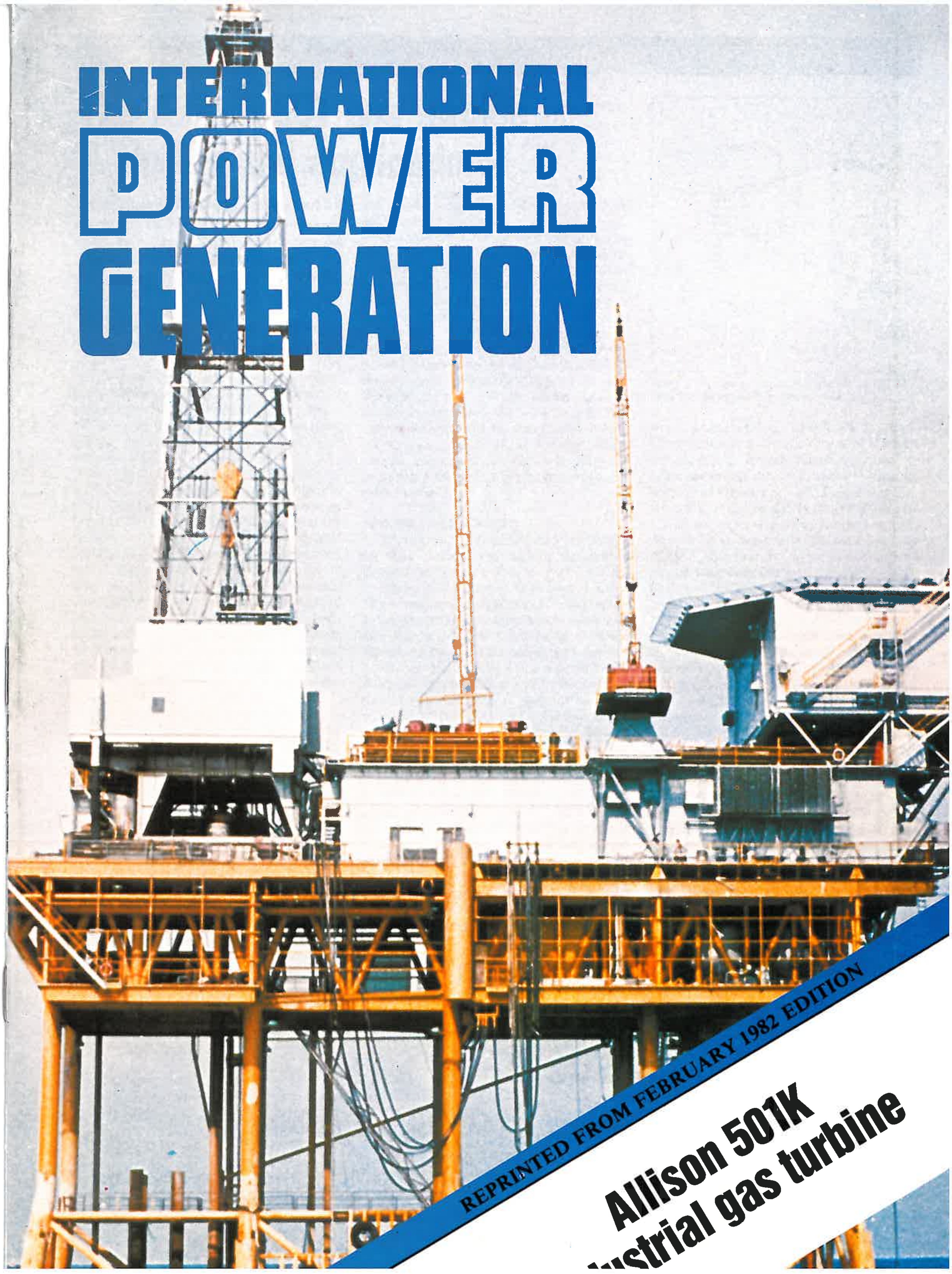
INTERNATIONAL POWER GENERATION



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Allison 501K
ustrial gas turbine

The Allison 501 gas turbine – design and applications

The Allison 501 series gas turbine which forms the subject of this month's wall-chart is a lightweight aero-derivative engine which has come to be used for a wide variety of applications worldwide, both for electric power generation and mechanical drive.

The 501 was first qualified in 1954 as a military aircraft engine following some years of design and development. 1955 marked the introduction of the first production engine. It was several years before the first industrial engine was produced but behind the scenes an industrial development project was being carried out to suit the erstwhile aero engine to its new life.

In 1962 a 501 industrial engine was installed as a gas compressor for the Natural Gas Pipeline Company of America at Woodward, Oklahoma. In the same year the company installed its own combined heat and power (CHP) system with a 501 gas turbine driving a generator, waste heat being recovered in a boiler. This engine was used for development, particularly emission control and multi fuel burning including experiments with methanol, heavy fuel and crude oil. The unit is still in existence, meeting part of the factory power load and still acting as a test bed, but for reasons which will be explained no longer as a CHP system.

Since the Series 1 and 2 engines of the early 60s the 501 has gone from strength to strength, practically every year seeing an extension of the industrial power market with projects being undertaken all over the world by DDA's distributors in different countries.

On the industrial side the 501 now has a stablemate, the 570 introduced in the mid 1970s. Development work on the 501, now in its Series 3 form continues and the Series 4, which is presently in an early stage of development and which will be put into production in two to three years time, will carry the engine design forward with a considerably reduced heat rate.

The Allison Gas Turbine organisation, since 1970 termed the Detroit Diesel Allison Division of General Motors Corporation, has its base at a vast site in Indianapolis, USA. The company has been a division of General Motors since 1929 but can trace its history back to 1915, long before the gas turbine age dawned. The company was founded in 1915 adjacent to the Indianapolis Speedway of motor racing fame to produce components for racing cars. When America became involved in the First World War Allison switched the company's activities to producing jigs and fixtures for the Liberty aircraft engine. In the post-war years the company's fortunes were built around aircraft engines.

Gas turbine pioneers

Jim Allison, the founder, died in 1929 and his firm became the Allison division of General Motors. In World War Two the company built a factory on its present site at Maywood on the outskirts of Indianapolis and as gas turbine power plants became feasible Allison became involved in their developments to such an extent that the first American jet fighter plane of 1945 was powered by an Allison gas turbine. Since then the gas turbine has come to form the mainstay of Indianapolis Operations activities (transmissions and diesel engines are also built there) and to date some 60 000 engines of all types have been delivered. Production capacity has doubled and redoubled so that presently the capacity is 250 turbines per month of all sizes from 300-12 000 kW output. Industrial gas turbines are produced at a base rate of 10 per month on a precommitted schedule, with an ultimate production capacity of 40 per month for the 501 K industrial engine and around 20 per month of the 570 K industrial unit.

One of the most significant events in the development of the Model 501 for non-aeronautical use was the choice of the unit for supplying the shipboard electrical requirements of the "Spruance" class of destroyers for the US Navy. Design and construction of the complete 2000 kW generator set packages was largely in the hands of Stewart and Stevenson Services Inc, an Allison distributor. Strict specifications placed severe demands on the ability of the basic gas turbine unit to withstand salt air corrosion and heavy shock loading (up to 16g).

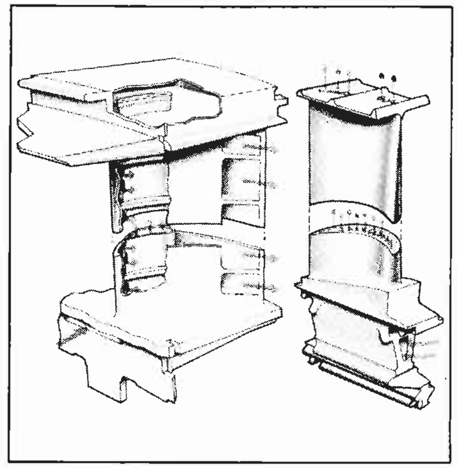


Figure 1. First stage vane and blade for the 501 K showing the internal air cooling passages

Much of the experimental work in producing sulphide resistant coatings for blading was done on DDA's CHP unit. The result was the so called ALPAK process, reviewed later, which is now applied as a standard coating process to all the industrial gas turbines produced by the company. The heavily contaminated air and fuel fed to the gas turbine in the course of this work spelt the end of the CHP system: the heating surfaces in the boiler proved rather less capable of withstanding the contamination than did the gas turbine, which resulted in the waste heat recovery section of the factory unit being pensioned off.

The original rating of the 501 K in industrial form was 1800 kW, this has been doubled in the course of development and much of this capacity for uprating can be

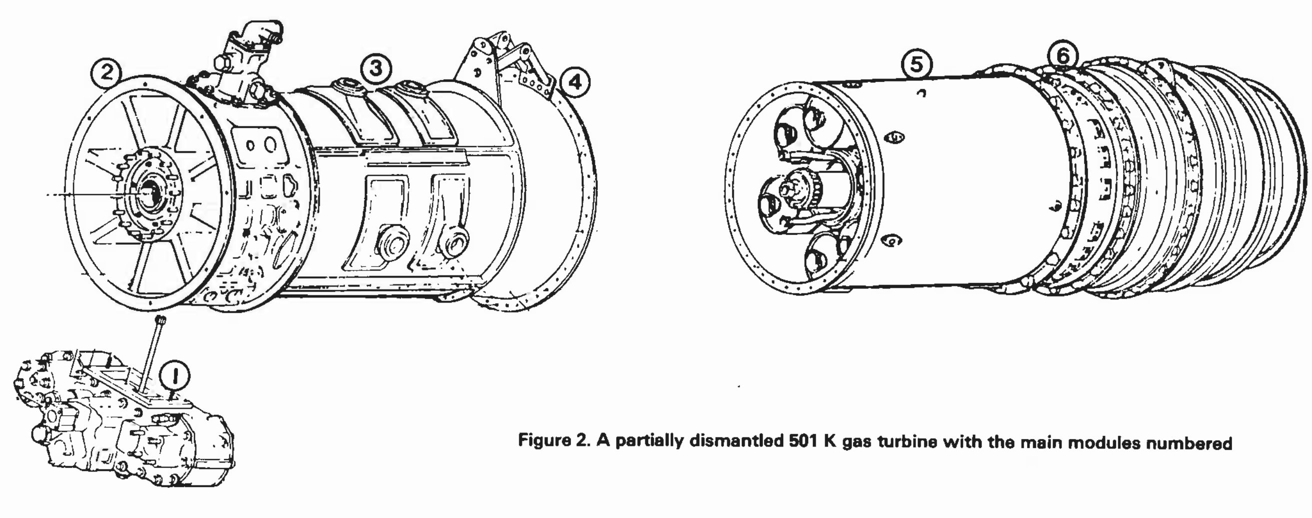


Figure 2. A partially dismantled 501 K gas turbine with the main modules numbered

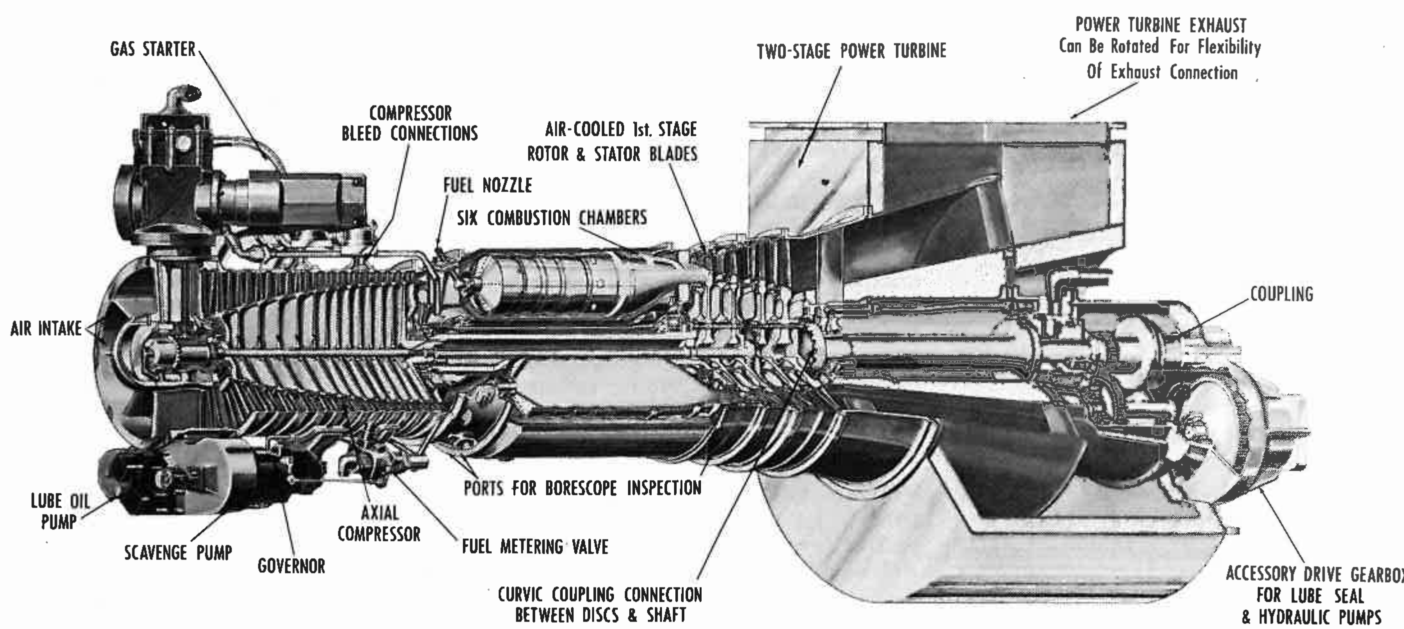


Figure 3. An Allison 501 K arranged as a gas generator feeding an Ingersoll Rand power turbine. This power unit is intended for driving gas compressors

traced in the use of air cooled blades and vanes in the turbine.

The air cooling technique involved the developments of precision cast blades and vanes with cooling air passages and internal finning forming part of the cast structure of the component.

DDA pioneered this technique, originally producing blades in their own works though nowadays precision cast blades of the required standard can be obtained through other suppliers. The company still maintains a precision casting facility, including vacuum melting furnaces, lost wax process and the provision of soluble ceramic cores for integral air passages. This gives DDA the ability to carry out their own research into improved blade cooling methods for new generations of turbines and also improved production methods.

Engine design

The 501 K engine is based on an axial compressor, multiple can combustors and an axial turbine. The compressor has 14 stages with air bleed valves for starting at the 5th and 10th stages. The compressor casing is horizontally split for access and an aluminised inner surface is provided, the rotor blading originally being fitted with zero or negative clearances so that the blade tips machine their own path through the soft coating to give minimum tip losses. Six combustor cans arranged around the centre section can burn oil or gas or both. Like all gas turbines of this size and type the 501 is designed for distillate fuels, with good filtration, such as grades JP4 or JP5 or ASTM D2880 No. 1 GT fuel. Natural gas with a heat content in the range 700-1400 Btu/SCF LHV can be burnt with suitable adjustments and the engine is normally rated for a heat value of 1000 Btu/SCF at a supply pressure of 17 bar.

In the single shaft version as supplied for electricity generation the turbine has four stages, the first stage blades and vanes being air cooled. These aerofoils are precision castings with internal air cooling passages and fins for internal distribution of the air. Approximately 1 per cent of the engine air flow passes through the hollow blades to give a metal temperature reduction of about 93°C at full power; 2½ per cent of the engine air flow passes through the stationary vanes where it is distributed by six small jets impinging against the inside surface of the leading edge of each aerofoil, the air then flows to the rear past the internal fins and leaves near the trailing edge of the vane. This cooling is sufficient to reduce the surface temperature by 176°C.

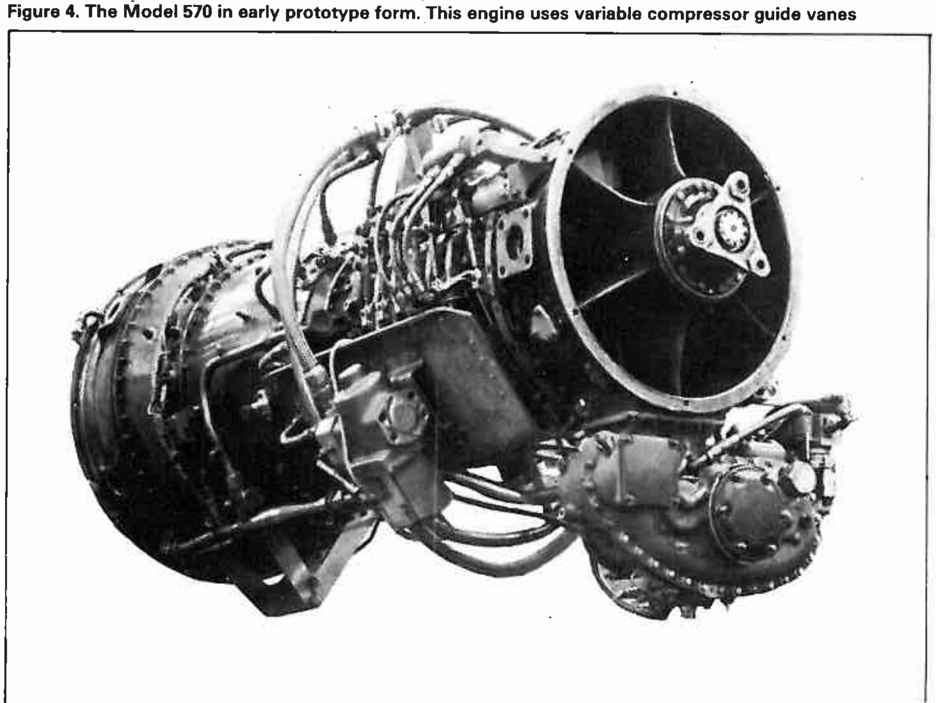
The use of a single shaft for electricity generation, with the drive taken from the cold end of the unit, is considered to give a more stable response to changing loads.

For some mechanical drive applications it is desirable to have an independent power turbine. In this case the gas generator section comprises the compressor and the first two stages of turbine blading on a single shaft, the second two stages of turbine blading being the power turbine. Creusot Loire in France and Ingersoll Rand and Stewart and Stevenson in the USA have developed their own power turbines, particularly suited to driving gas compressors. These power turbines are designed to accept the 501K as the gas generator section.

The compressor and turbine rotors in the 501K are supported in rolling element bearings with the residual thrust taken at the bearing between compressor and combustion section. Auxiliaries are driven by bevel gear and shaft from the compressor inlet end and in single shaft versions this end is also the output shaft.

As outlined above DDA developed a coating for blades and vanes to provide sulphidation protection at high firing temperatures. This proprietary process, known as

Figure 4. The Model 570 in early prototype form. This engine uses variable compressor guide vanes



ALPAK, consists of the diffusion of aluminium into the blade and vane metal surfaces. This gives a protective.coating some 0.05mm thick which will form a self healing oxide film which resists further oxidation of the surface and protects the substrate metal from sulphates in the gas stream. These sulphates, which otherwise cause severe corrosion of aerofoil sections particularly at the leading and trailing edges, can result from a number of pollutants. Sodium and sulphate ions will be present in salt water, from sulphur in fuel, sodium sulphate in cleaning solutions and sulphur dioxide in industrial atmospheres. On occasions sulphur bearing particulates may be present in the air as a result of other industrial processes.

Modular construction

The 501 can be split into a number of modules for maintenance and major overhaul. The basic modules are: the accessory case, the air inlet, the compressor section, the transition piece, combustor section and the turbine section. The Series 4 unit at present under development will retain the same frame size and many identical components to the Series 3 501K. A further stage of blades and vanes will however be air cooled and there will be changes to the aerodynamic profiles of compressor blading and to the combustors giving better component efficiencies and allowing a higher firing temperature. DDA say that Series 3 machines can be converted to Series 4 in due course, should this be desired, on the basis of module interchange or major modification.

Model 570

The 501's stablemate, the 570K, is a more powerful unit of somewhat different design. This turbine was introduced in 1975 after a development programme initiated in 1968. The 570K is built for a thermal efficiency of over 30 per cent at continuous power and this efficiency is maintained within 2 per cent over the top 40 per cent of the power range.

The 570K is built only in two shaft form for all purposes and in electric power generation guise is rated at 4.5 MW generator output for base load duty.

A 13 stage compressor is used with a 12:1 pressure ratio and variable stator vanes are used in the compressor. A two stage turbine with air cooled rotor and stator vanes drives the compressor, combustion taking place in an annular combustor. The free power turbine comprises two turbine stages with output shaft drive from the cold end of the unit. Like its smaller brother this engine is suitable for liquid, gas or dual fuel operation and extensive use of protective coatings is made.

Stationary and mobile power generation

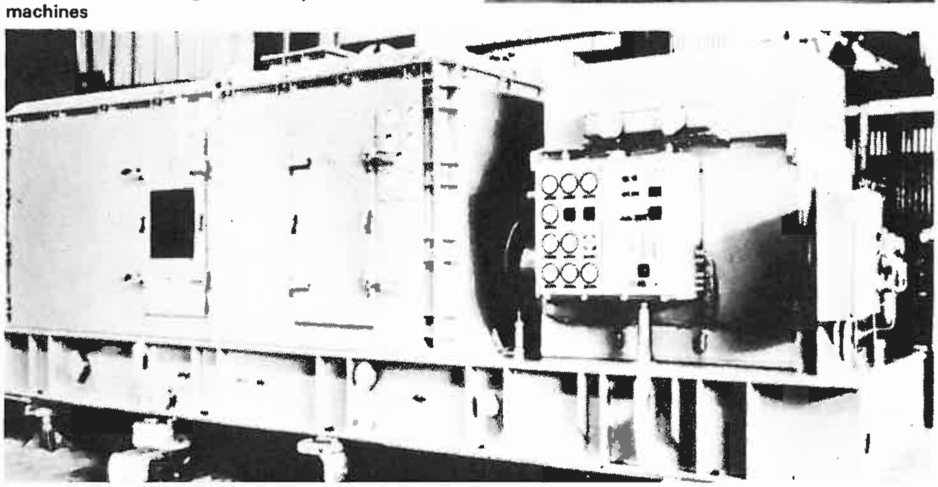
Since the type 501 gas turbine can deliver in excess of 3 MW from a compact yet heavy duty package it has been favoured particularly for applications where weight or space are at a premium. Ranking high among these are mobile generator sets with the gas turbine generator packaged within a profile meeting road haulage regulations for semi-trailers.

IPG recently covered (October 1981) a three trailer 4 MW road transportable set from AMAN in France. This was based on one trailer with a 570 powered generator set, a second trailer housing the switchgear and a third fuel tanker. The first of these has now been delivered to its French owners.

On similar lines but built around the 501KB turbine is a series of seven trailer mounted power plants built by Centrax Gas Turbines in the UK. The 501K single shaft Allison turbine is geared to a Brush AC generator through an Allen epicyclic gear, this gives a very short layout such that the generator set, auxiliary power unit, switchgear and inlet and exhaust trunkings can be fitted into a single 40ft trailer, weighing 30 tons. The set is started by a Deutz diesel engine driven hydraulic pump system and the package can deliver 2500 kW at 50 Hz at the specified site conditions of 35°C and 450 m altitude. The fuel can be either diesel oil or natural gas.

To prevent trailer distortion from affecting the power plant alignment a light subframe carries the gas turbine, gearbox and generator, and this subframe is in turn mounted to the trailer frame by a three point anti-vibration mounting. As the 501 is a front drive unit, mountings at the compressor end of the engine allow for free thermal expansion. The Centrax type 350 mobile set has extensive acoustic treatment and if the optional exhaust extension is in place the noise level is less than 55 dB(a) at 30 m.

Figure 5. A US Navy 'Spruance' class destroyer. The development of Allison gas turbines for the packaged generator sets on board these ships (shown right) formed the basis for contaminant resistant blade coatings for subsequent industrial machines



Cogeneration in L.A.

The small gas turbine can be an attractive way of supplying power needs to large buildings especially when used in the cogeneration mode. Such an installation is one recently completed at the Los Angeles Times building in the city of that name. The heart of the system is an Allison 501K turbine driving a generator in a North American Turbine package. The unit produces about 3 MW of electricity, burning natural gas with distillate oil as a back-up fuel. Additional electric power is provided if necessary by two Detroit Diesel engines of 1100 kW each, maintained on standby. Waste heat from the gas turbine passes to a Deltak unfired waste heat boiler which produces steam at 0.95 bar. A Trane absorption chilling machine completes the system which together supplies all electrical, heating and air conditioning needs for the building while surplus power can be sold to the Los Angeles Department of Water and Power. As space was at a premium in this installation the plant is arranged as an outdoor system on a shelf at the edge of the roof of the building.

Natural gas is taken from the gas main at about 2.5 bar and compressed by a reciprocating compressor to 17 bar for injection into the combustors. The complete system is intended to pay for itself in five years and qualifies for the maximum $100 000 incentive under the South California Gas Award Programme based on the additional capacity avoided through fuel savings obtained by cogeneration systems.

A very different application is represented by the picture on the front cover, the drill rig Penrod 36. This rig was formerly on the Dutch sector of the North Sea and has since

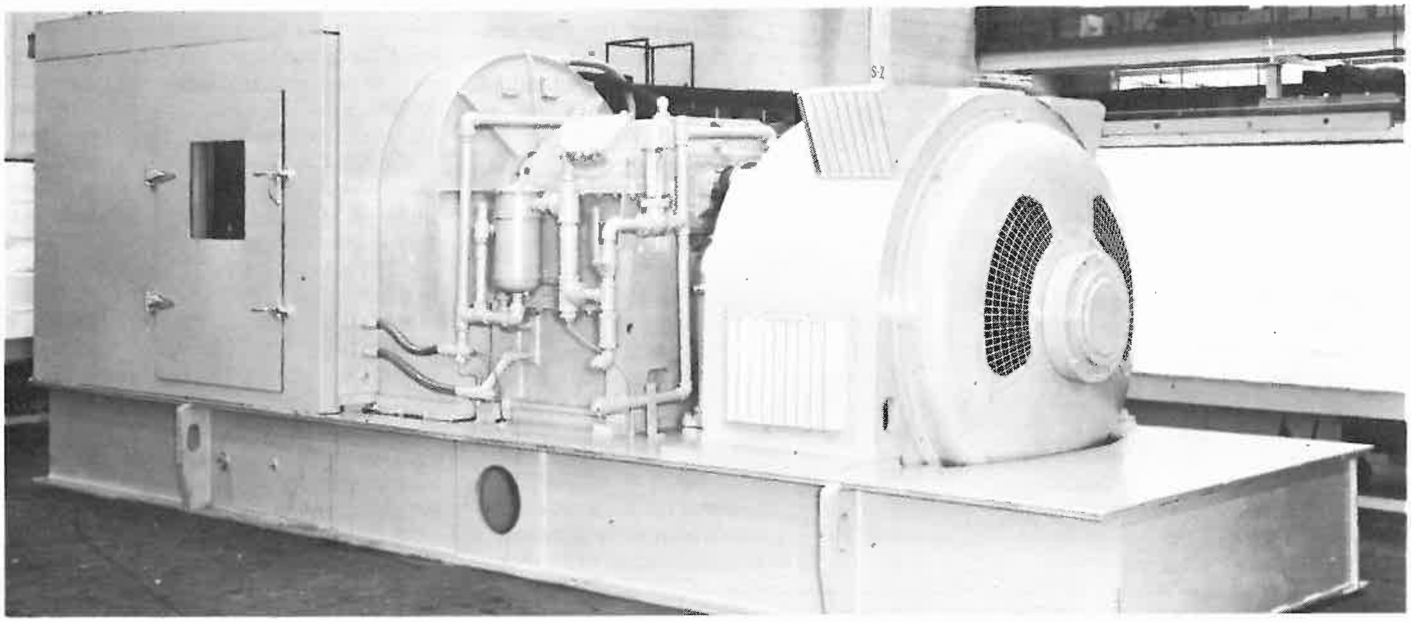


Figure 6. A typical skid mounted generator set with only the gas turbine section enclosed in an acoustic housing. This particular set was built for American Telephone and Telegraph Co

rigs represent a very severe space problem when it comes to power generation and the Allison 501 has proved to be a popular source of power for these structures. On Penrod 36 two 501K's on skid mounted packages provide all the power requirements for the rig. For this application the rating is about 2500 kW per set.

Early in its life the Penrod 36 power system suffered a severe setback when drilling mud was allowed to enter the fuel system in quantity, resulting in the destruction of the turbine fuel system. With both turbines out the rig was effectively at a standstill though basic emergency power was supplied by two Detroit Diesel generators to keep the drill string moving. A rapid engine exchange was, therefore, initiated and two new 501's were snatched from the production line and transported to the rig. The first one was installed so that within 36 hours of the breakdown the rig was back in action again. The cause of the disaster was firmly ascribed to the contamination by drilling mud and the rig's fuel supply system revised. Since then the life of the power system has been comparatively uneventful and each of the replacement turbines has now amassed some 50 000 hours of running.

Turbines for Egypt

Recently the Egyptian Ministry of Development chose DDA gas turbines for a major project in the desert. Desert land is potentially very fertile provided it can be irrigated and this project involves drilling a number of deep wells from which irrigation water can be pumped. With water supply ensured, the Ministry hopes to encourage settlements to form in this area north of Cairo, with homesteads in the rehabilitated desert and people tending the land, thus relieving the population pressure on the city.

To provide electricity for powering the deep well pumps seven Allison 570 powered generator sets are to be supplied. These are

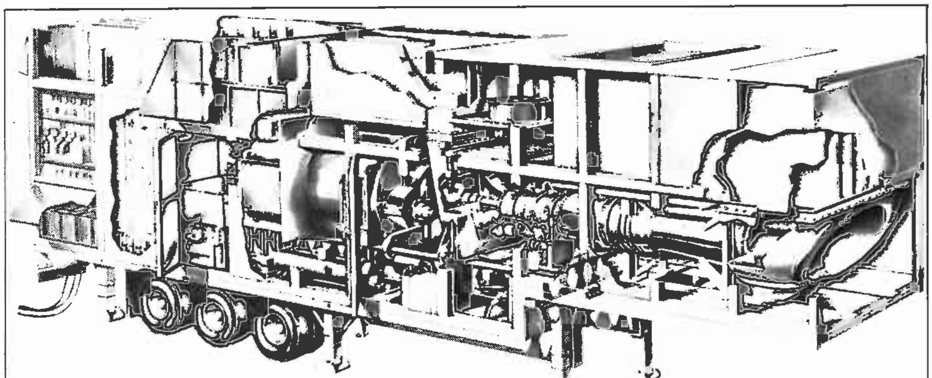
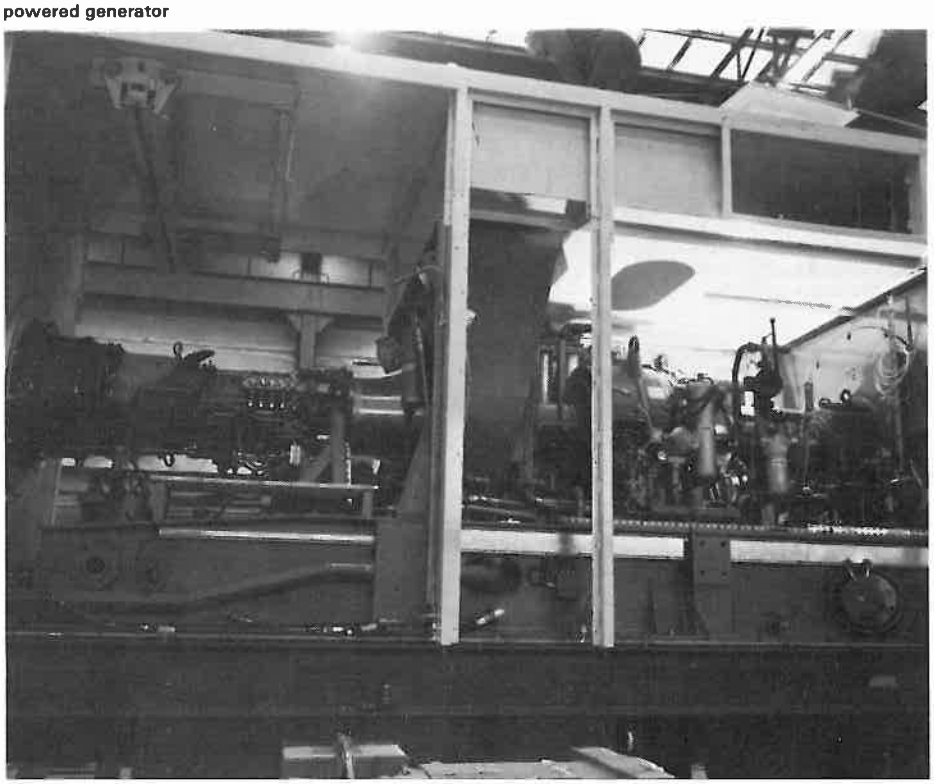


Figure 7. A Centrax Type 350 mobile generator set. The compact 501 K turbine allows generating and control equipment for 2.5 MW to be housed in a trailer 12.2 m long, weighing just over 30 tons

Figure 8. Interior of a mobile set by AMAN in France. 4 MW of power is produced by the Allison 570 powered generator



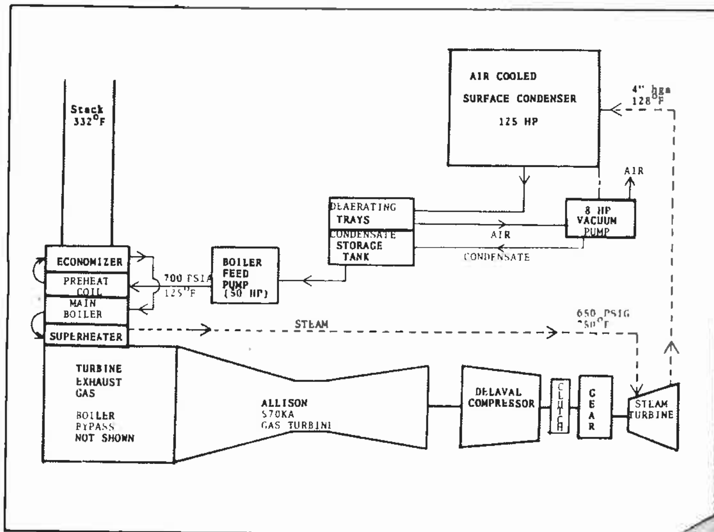


Figure 9. A Stewart and Stevenson combined cycle system for pipeline compressor duty. A Deltak boiler, Terry steam turbine and Graham air cooled condenser enables the site rating to be raised to 7646 hp from 5529 hp simple cycle

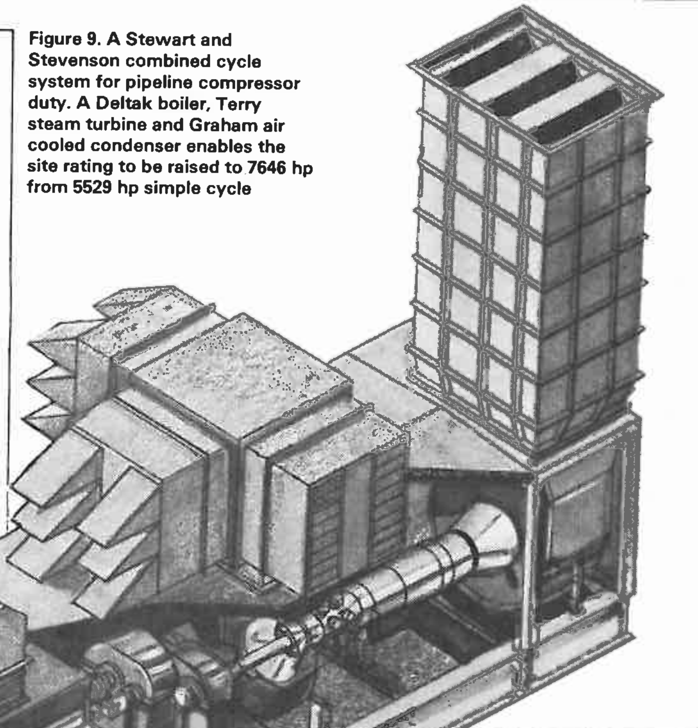


Figure 10. Transportable power plants built by Western Engine Co around an Allison turbine for use in the Egyptian irrigation project

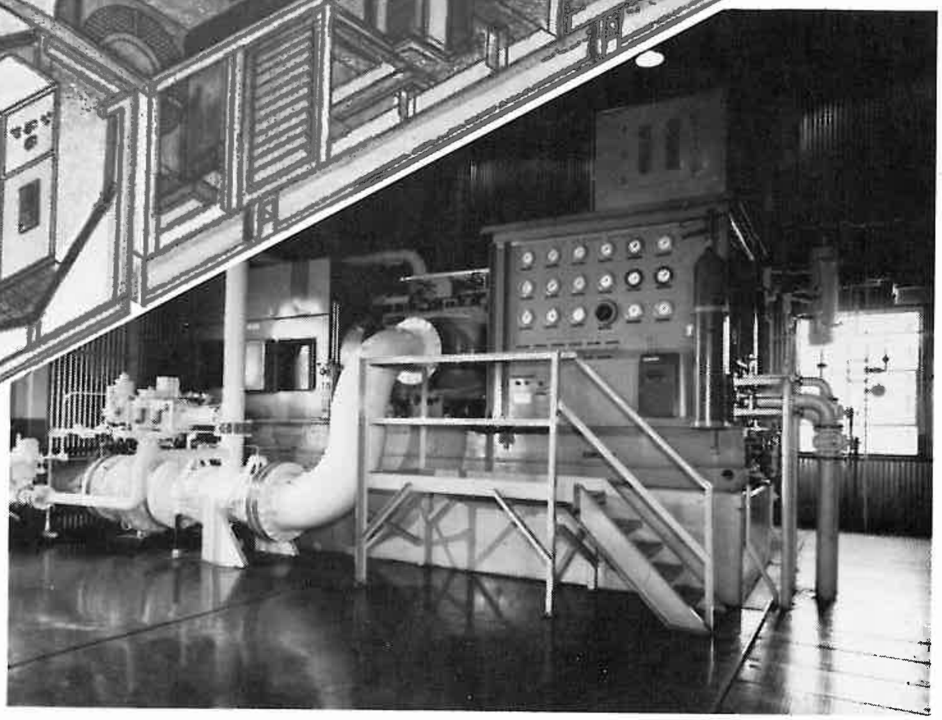


Figure 11. A 501 driving a De Laval compressor at a remotely monitored pipeline compressor station near Vernal, Utah, operated by Northwest Pipeline Corporation

power systems, Western Engine Co. of Itasca, Illinois, using Western Co. gears and Brush generators.

Since the sets must be hauled to the sites, light weight and compact dimensions were vital. In the operating area there will be few trained personnel, so reliability has been stressed and the units will be serviced in the field by the contractors.

It is expected that the units will run for some 4000 hours per year during the growing season, and the gas turbines will consume distillate fuel.

The project is the latest chapter in a history of Allison gas turbine power in Egypt which began in 1974. In that year 14 generator sets with an output of 2.5 MW at 11 kV, 50 Hz, powered by 501K gas turbines were ordered by the Egyptian Electricity Authority to supply power at various locations pending repair of the electricity grid disrupted in the 1973 war.

Sets were installed at Mersa Matruh, Alexandria, Port Said and Cairo. The bulk were built for haulage by tractor unit but three were mounted on barges.

The most heavily used units have been in the Port Said area where four sets were

thoroughfare, burning liquid fuel and operating in parallel with a number of diesel generators in the locality.

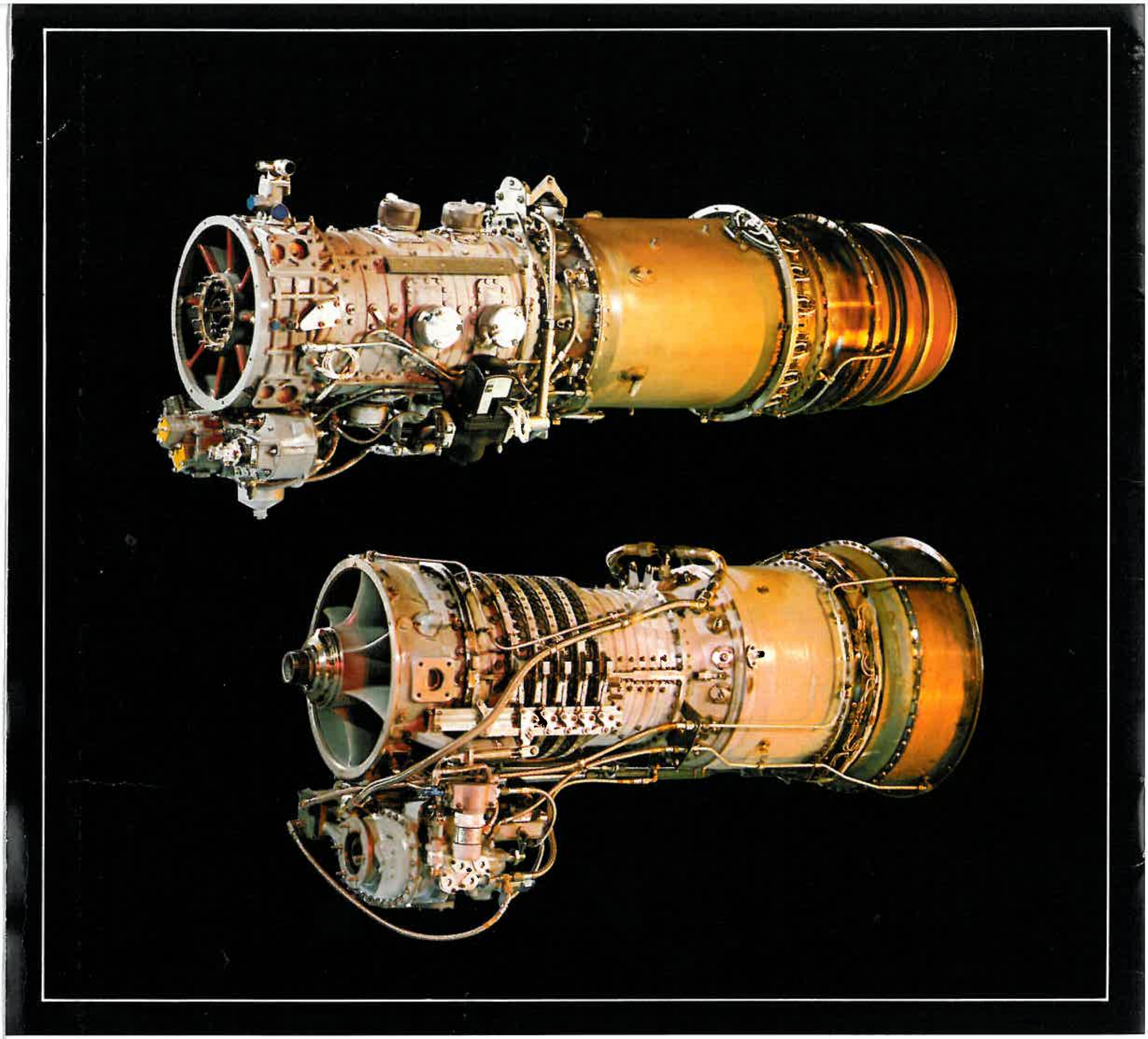
Several problems which affected these first Egyptian installations have led to solutions of wider applicability, some of an engineering nature, some relating to operator training and supervision.

One turbine at Port Said failed after 4000 hours running due to fuel nozzle clogging and torching of the hot section. The cause was found to be fuel filter rupture due to plugging by wax from cold Solar fuel. Once the filters became defective dirt could reach the fuel nozzles. It was found that the fuel heating system provided was not being used.

Later units were fitted with automatic fuel

while the scheduled maintenance scheme was altered to include changing nozzles in sets for clean ones at regular intervals.

In another problem area the gas turbine sets were cast in the role of victim, the same underlying fault also causing broken crank shafts in diesel generator sets at Port Said. Several high speed shaft failures in shear were experienced in the DDA sets and were found to be caused by the circuit breakers being closed without the set being in synchronism with the load bus. Both training and switchgear interlocking were improved to reduce the problem, and nowadays Allison powered sets are usually built with shear pin type low speed couplings which protect the high speed elements from



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