PACKAGING DESIGN OF THE RLM 1600 GAS TURBINE

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ABSTRACT
The LM 1600 Gas Turbine has proven to be an excellent engine when packaged in compliance with GE's design recommendations. A packaging approach has been developed by European Gas Turbines which maintains a standardized core-engine installation for the package, while still retaining the capability to be easily reconfigured for inlet and exhaust duct routings, underbase designs and driven-equipment options. This paper presents an overview of the design goals of the package along with specific examples of their execution. Graphics of the package features and build sequence are included along with some current applications.

INTRODUCTION
A gas turbine engine is "packaged" by starting with what is known as a "core" engine (gas generator and power turbine) and adding the remaining components to provide a total gas turbine driven machinery installation. Each type of gas turbine (hot-end drive, cold-end drive) has a range of applications which will determine the package features.

The LM 1600 core-engine [ISO rating 18,750 HP (14 MW)] is a 3-shaft hot-end drive turbine with a 2-shaft gas generator and aerodynamically coupled free power turbine. The nominal output shaft speed of 7000 RPM makes it suitable as a direct drive pipeline compressor driver, among other applications.

Major Design Goals
The major design goals for the RLM 1600 package (Fig.1 & 2) were:
- The underbase design had to allow for being either free standing from the driven unit or for bolt-up underbases.
- The acoustic enclosure had to allow a top or end combustion air inlet, and exhaust at either side horizontal, vertical, or phased.
- Ventilation of the engine enclosure had to evenly cool the core engine.
- The package assembly sequence had to be a build up of major modules to reduce final assembly time and space requirements.

Fig. 1
RLM 1600 Gas Turbine Package

Fig. 2
Enclosure & Wing Cabinets Open

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- The completed turbine package had to allow transport with the core engine installed for normal overland conditions. The overall size had to be kept within reasonable road handling proportions.
- The unit had to be easy to service and require minimal special tooling.
- To simplify field piping & conduit hook-up, most off-skid connections, both mechanical and electrical, had to be grouped at the non-drive end of the machine.
- The number of on-skid systems would be maximized to minimize field installation time.

History of the RLM 1600 Package

The package design of the RLM 1600, starting in 1989, had to allow for maximum customization without being inordinately expensive. This includes not only brands of components but layout, electrical area classification, and agency approvals (CSA, Lloyd's, RINa, etc.). In some package designs, the electrical interface installations often become crowded due not only to the general proliferation of on-skid devices, but also to the increased customer interest in separate junction boxes and spare terminals. Additionally, package mechanical interface connections have sometimes been brought out in areas which infringe on service access.

The first RLM 1600 package departed from our previous packages in several other areas. There was an effort to procure some major package components (air filters, acoustic package, major electrical components, off-skid, packages, etc.) either from our traditional suppliers or others local to our customer's area. Vendors of off-package components were required to simplify field assembly to reduce installation requirements. The main simplification effort went into air filtration. A foundation system which did not require shimming or vertical jackscrews for turbine leveling would also be used.

Contract-specific and internal testing programs have been in use since 1990 to prove the integrity of the various RLM 1600 package configurations. This has included full speed and load tests against a water brake, full load generator set tests, transient speed and load studies, and enclosure ventilation temperature/flow distribution testing.

Some Example Applications

Four examples of the types of applications which have been built are:

1. The first installation consisting of two pipeline compressor drivers for installation in Ontario, Canada each driving a 830 MMCFD (23.52 MMSCFM) compressor through a torque measuring coupling.
2. A pipeline compressor driver order for seven units in Alberta, Canada with compressors ranging from 490 to 3,084 MMCFD (13.8 to 87 MMSCFM) each. These compressors are equipped with magnetic bearings.
3. A generator installation for three 14.5 MW units which are part of the main electrical propulsion system on a semi-submersible production and drilling platform being built in Italy. This installation also includes waste heat recovery.
4. A generator installation for two 13.9 MW units which exhaust into waste heat recovery boilers for a university in California. The air filtration system is equipped with inlet air cooling.

PACKAGE DESCRIPTION

<table>
<thead>
<tr>
<th>Typical Sizes &amp; Weights</th>
<th>L (ft.)</th>
<th>W (ft.)</th>
<th>H (ft.)</th>
<th>Wt. (lb.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Pkg. (standard)</td>
<td>24(7.3)</td>
<td>12(3.7)</td>
<td>13(4)</td>
<td>60,000(27,223)</td>
</tr>
<tr>
<td>Drive Pkg. (tall skid)</td>
<td>24(7.3)</td>
<td>12(3.7)</td>
<td>14(4.3)</td>
<td>68,000(30,853)</td>
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<tr>
<td>Genset (single lift)</td>
<td>46(14)</td>
<td>12(3.7)</td>
<td>13(4)</td>
<td>190,000(86,207)</td>
</tr>
</tbody>
</table>

Basic Unit Arrangement

The RLM 1600 standard package arrangement (Fig.3) consists of the core engine mounted on a W30 steel underbase, an engine enclosure/air inlet plenum assembly and two "wing" cabinets. The wing cabinets contain the lube oil system on the left side (when facing output shaft) and fuel instrumentation, pumps, filters and compressor-wash system on the right side. Fuel valve assemblies for liquid and gas are located in ventilated compartments in the underbase. Pipe, tubing, and conduit from the wing cabinets run below the plenum to the engine enclosure.

Core Engine Support

The core engine is supported in 5 places on a series of links and spherical bearings which are constrained in 2 planes only at the right rear engine mount allowing the core engine to move freely with the underbase if there is a forced underbase flexure.
The power turbine and gas generator are lifted and installed separately. This required the design of an alignment cradle to allow for link installation and removal while the gas generator and power turbine are held in center line position. The exhaust collector is supported on its own link and clevis system and seals to the power turbine with two piston ring seals, allowing a wide variation of exhaust orientations.

**Wing Cabinets**

On-skid support systems such as lube oil, fuel instrumentation, and compressor wash system are housed in the two wing cabinets adjacent to the air inlet plenum. These cabinets are also the mounting surface for the electrical junction boxes for field terminations. All exterior sides, other than the junction box mounting area, have doors or bolted covers.

The lube oil cabinet (Fig. 4) houses the lube oil tank which is set at a height to flood the suction of the two engine-driven lube oil pumps. Pressure and temperature gauges are located on a panel attached to the lube oil tank. Oil filters for the two oil pumps and the main return line to tank are located in the bottom half of the cabinet. Pressure and temperature switches and transmitters are located on the top left side above the filters. Electrical conduit runs are kept to the side and rear of the cabinet to allow easy access to the devices.

The fuel wing cabinet houses the gas fuel instrumentation and the liquid fuel pump and filters in the case of a liquid fuel or dual fuel engine. The liquid fuel pump motor is in a separate compartment of the wing cabinet to isolate it from the fire system zone due to motor cooling requirements. In the case of a gas fuel only engine, the compressor wash system (consisting of a solution tank and a rinse tank) is located where the liquid fuel components would have been. In the case of liquid or dual fuel, the compressor wash system is located off skid on its own skid or trolley. Tubing penetration areas to the turbine enclosure at three separate elevations insure that low pressure sensing lines can be run and devices positioned without traps in the lines.

**Acoustic Enclosure and Air Inlet Plenum**

The RLM 1600 can be built with or without an acoustic enclosure (Fig. 5) with no change to the plenum and wing cabinet construction. The standard enclosure is designed for 85 dBA at 3 ft. (1m) The mounting area for the acoustic enclosure allows for a thicker wall construction than the 4 in. (100mm) standard if an 80 dBA design should be needed.

The enclosure has large double doors with a removable center post on both sides. The doors have double acoustic seals and one tempered glass double pane window on each side of the package. Rear access door(s) are also provided depending on exhaust orientation to access the drive coupling area. The service gantry beam, when field installed, is supported inside the enclosure by a permanently mounted trolley, outside by a removable trolley assembly which bolts to the side of the enclosure, and a wheeled "A" frame. This allows both a low clearance assembly and adequate structural support for extending the beam to straddle the gas generator or power turbine transportation containers.

Fire suppression is provided by a Halon 1301 or CO₂ system with optical and heat detectors. Discharge nozzles are located in the enclosure as well as both wing cabinets. All three areas have their own overpressure relief protection. Gas sensors are located in the enclosure and in the fuel wing cabinet.

**Enclosure Ventilation Flow Diagram**

![Enclosure Ventilation Flow Diagram](image_url)
Enclosure ventilation (Fig.6) can be either a positively or negatively pressurized system depending on the electrical area classification and customer requirements. In the case of a negative pressure system, timed vent fan inhibit switches are provided both inside and out to allow entry or exit from the package during operation. Ventilation air is drawn from a separate filter to the combustion air inlet depression or possibly allow backflow of hot enclosure air to the engine inlet. Half of the ventilation air is discharged in the forward part of the enclosure while the other half is ducted to two compartments formed by decking the skid and discharged below the engine and in back of the exhaust collector. This provides positive ventilation of the entire enclosure with the exit point being above the power turbine. On-engine devices are kept well within their design temperature limits while off-engine devices in the skid are cooled directly. Silencers are typically located ahead of the vent fans and after the enclosure vent exit. Vent fans can be single, dual, 2 x 100%, 2 x 50% and with a DC changeover fan if the site has a requirement for a backup AC generator to start during a site power outage. For extremely cold climates, a vent recirculation duct is provided with a temperature controlled damper to regulate the ventilation inlet temperature during cold ambient conditions. Additionally, thermal lagging is provided on the firewall between the engine enclosure and inlet plenum to eliminate heating of the plenum area, which is an area of potential ice build up.

Lube Oil System
The lube oil system within the engine enclosure (Fig.7) has been minimized to have only those components which must be near the core engine. The LM 1600 core engine has anti-friction bearings in both the gas generator and power turbine. The common lube oil system for both uses synthetic oil supplied by two gear-driven individual pumps (no motor driven pumps are required) and returned to the lube oil tank by three gear-driven scavenge pumps. All connections to the engine are via Teflon lined, stainless steel braided flex hoses with hydraulic "quick connects" just below top of skid. These provide a positive method of sealing off the oil lines during servicing both to eliminate the need for any valving which might be left closed accidentally and to prevent contamination of the lines. Three of the bearing compartments are vented to atmosphere. These are routed first through an air cooler in the vent air stream to reduce the temperature for improved separation efficiency and then to an air-oil separator before being vented to atmosphere. This not only reduces visible emissions to a minimum but recovers most of the oil mist for return to the main lube oil tank.

Lube oil coolers can be provided as single shell & tube type mounted to the package underbase, dual shell & tube on a separate stand, or air blast type remotely mounted. The air blast type can be provided winterized if necessary.

The driven unit generally uses a mineral oil system which is located on a smaller skid near the driven unit for free-standing turbine drivers and on the driven unit portion of the package for bolt-up units. Where gear driven main supply pumps are needed, they can either be driven from a pad on the load gear, or from a reduction gear drive on the driven unit itself. Since many compressor manufacturers now offer magnetic bearings, a driven unit lube oil supply is then not needed.

Gas Fuel System
The gas fuel system (Fig.8) consists of a block and vent system at skid edge, out of the engine rotating plane, followed by a gas fuel regulator (if required) and the remaining valve train within the underbase right side compartment. Valving is positioned to allow top servicing by removing the deck plate. The decking in areas which require component adjustments is held in place by latches which can be opened easily by hand. Gas fuel flow metering, if required, is provided off skid.

Liquid Fuel System
The liquid fuel system (Fig.9) also begins with a fire system block valve at the skid edge and continues within the fuel wing cabinet with the boost pump, duplex filters, and supply pressure instruments. The fuel is sent to the left side compartment where
the liquid fuel valve train is located. This operates on a separate actuator from the gas fuel valve to allow smooth changeover from gas to liquid fuel and vice versa. This valving is easily serviced by quick removal of the deck plates on top of the skid.

![Diagram of fuel valves and filters]

**Fig. 9**
Liquid Fuel Supply To The Engine

**Start Systems**

The gas fuel supply can also be used for a gas expansion type starter motor. Like the fuel valve train, a block and vent system is located off-skid followed by a pressure regulator. The regulated gas supply to the starter motor is protected by a relief valve which will prevent overpressure of the starter motor casing in the event of a regulator malfunction. A hydraulic start option is also available which uses an off-package hydraulic start skid, either AC motor or diesel engine driven.

**Combustion Air Inlet System**

The combustion air inlet plenum can be built in either of two configurations.
- Top inlet air entry including an inspection door, with window and plenum light on the end wall
- End inlet air entry with a top mounted light and access cover and an inspection window in the fuel wing cabinet.

In either configuration the plenum floor is made of stainless steel plate to prevent paint chips or rust from entering the engine, which might occur if a carbon steel floor were used. The air inlet bellmouth is protected by a wire screen with a nylon protective sock, in accordance with GE's latest recommendations. This prevents foreign object damage from any loose objects inadvertently left in the air inlet system or inlet component failure.

![Typical Exhaust Silencer And Air Filter]

**Air inlet filtration** (Fig.10) is available in a wide range of barrier or self cleaning filter designs. Three of the approaches which have been used to date are:
- A single stage self-cleaning filter with a separate vent section built as a single module with access platform and support legs assembled on site.
- A three-stage marine air filter system also built as a single module but with an exhaust heat anti-icing heat exchanger at the inlet face. The vent section is separated after the anti-ice heat exchanger and the first filtration stage.
- A two stage barrier filter with a chilled water cooler.

Under certain conditions, the engine requires the protection of an anti-ice system. This design uses exhaust gas cooled by mixing with ambient air and drawn through the in-line heat exchanger in the air inlet by an extraction fan which then re-injects the cooled exhaust into the combustion air exhaust duct. This can be adjusted for the desired temperature rise in the inlet air and has the added benefit of reducing a loss of performance in the ambients below 25°F (-4°C).

Air inlet silencers have been built in several configurations depending on site requirements. Single or multiple rows of splitters as well as "blocked line of sight" configurations have been built.

![22 1/2° Exhaust in a Pipeline Compressor Building]

**Combustion and Compressor Bleed Air Exhaust**

The combustion air exhaust orientations available from either side to vertical or phased allow the RLM 1600 to be easily set up for simple cycle or heat recovery applications. A popular build configuration for pipeline compressor applications (Fig.11) is 22 1/2° right side which allows easy walk around clearance and exits a single unit building low enough in the wall to allow one overhead crane to cover the whole building. Exhaust diffusers are built either symmetrically for side or phased exhausts and offset for vertical exhausts due to enclosure roof clearance requirements. Far field silencing requirements built so far have included systems for 70, 60, and 46 dBA AT 500 ft. (150m). The variable bleed valves (VBVs) can be configured to discharge low pressure...
compressor discharge air through a separate duct and silencer to atmosphere or into the main combustion air exhaust, depending on site exhaust back pressure and/or noise constraints.

**Unit Control Panel**

The company produces a microprocessor based control system (Fig. 12) which can be offered in a variety of cabinet configurations for remote mounting from the turbine. This system can readily interface with such control devices as Programmable Logic Controllers (PLCs), distributive control systems (DCS), and industrial computer based controls.

The unit control panel will typically house a (Visual Display Unit (VDU) to display engine status and data, alarms, and shutdowns. Additional control and monitoring equipment will be included as defined by contract specifics, as related to engine and driven equipment.

**Options Supplied To Date**

Examples of some of the features which have been incorporated into various RLM 1600 installations are:

- A fuel gas cooled shell and tube lube oil cooler for the turbine synthetic oil.
- A foundation system of isolation pads which allows some foundation flexure without resorting to a 3 point mount system.
- Build modifications to allow operation of a genset at 22 1/2° from horizontal in any direction. This was a requirement for the main electrical propulsion generators (Fig. 13) on a semi-submersible platform.
- Acoustic enclosure modifications to an AO class fire rating.
- A water injection skid including boost pump, filtration, control valving and instruments.
- RINa type approved certification
- Lloyd’s certification for offshore installation.

**CONCLUSION**

The design of the RLM 1600 package is a flexible system which can be readily configured to new applications. The company will be offering a Dry Low-NOx combustion system (estimate 1995) as well as other improvements which will speed field installation, such as fiber-optic cabling on controls. Additionally, with the advent of a new industry standard procurement specification for packaged gas turbines, API RP 11 PGT (May 1992), the RLM 1600 design, construction, and documentation will change to meet this new standard wherever feasible.

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**REFERENCES**