PACKAGE DESIGN FOR A 5500 BHP AERODERIVATIVE INDUSTRIAL GAS TURBINE

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ABSTRACT
The Cooper-Bessemer Rotating Products group of Cooper Energy Services has designed an all-new industrial gas turbine / compressor package based upon the Allison Engine Company 501-KC5 gas generator with a two-stage industrial power turbine. The latest project management techniques were employed to reduce design cycle time while optimizing total product quality, manufacturability, and reliability. The resulting gas turbine / compressor package is a low-risk, technologically conservative approach, designed to avoid the problems often associated with new product development.

INTRODUCTION
Through its Cooper Energy Services (CES) Division, Cooper Cameron Corporation has had a longstanding joint venture relationship with Rolls-Royce to market Cobren® aeroderivative industrial gas turbines based upon Rolls-Royce gas generators with CES power turbines, compressors, and packaging. After the purchase of Allison Engine Company by Rolls-Royce in 1995, the decision was made to incorporate the Allison line of industrial gas turbines into this partnership. The first new product to be available as a result of this decision is the Cooper Rolls CR501-KC5, a 5500 BHP gas turbine specifically aimed toward mechanical drive applications in the oil & gas industry.

The process used to design this new product would be a function of the goals chosen for the product itself. It was perceived that the lower-horsepower segment of the gas turbine market had somewhat different demands than those that applied to the larger Cobren® line. For example, the target market is seen as demanding shorter overall procurement cycle times, expecting a higher degree of product standardization, and being more highly price-sensitive. These are in addition to the ever-present demands for high reliability and efficiency. The design process had to be optimized to produce a product that met these and many other demands. The first step in deciding the design process was to set the specific product goals.

PRODUCT GOALS
The goals set for the new package design were based upon past industry experience, shaped by perceptions of the expectations held by the target market segment. These goals include:

- High overall reliability and availability. Excess compression capacity is no longer a characteristic of the natural gas industry, and the cost of equipment downtime is relatively high. Maintainability is an important component of overall availability. Ease of maintainability must be incorporated from the outset of product design, it cannot be added later.

- Total cost effectiveness, including not only the initial cost of the equipment but also the costs of installation and commissioning, operation, and overhaul.

- Short delivery cycle, including all phases of a project from initial inquiry to arrival of equipment at site. It was quickly recognized that there are important product design features that can facilitate shorter lead times. This approach alone, however, would not achieve the same lead time reduction that would be possible if corresponding changes were made in the procedures used to manage the flow of work through the engineering and manufacturing phases. A comprehensive effort to shorten cycle times would involve redesign of procedures across a broad spectrum of the business.

- Minimum installation and commissioning effort. Installation and commissioning can be a hidden cost that contributes substantially to the overall cost of a project.

- Ecological friendliness. This includes minimizing not only exhaust emissions, but also noise, and any other factors that could make a gas turbine installation a bad neighbor.
- **Flexibility of application.** Several package configurations would have to be available to meet varying customer preferences. Installations may be indoors or out, on- or off-shore. Mounting locations for inlet, exhaust, and control systems will vary. Power available may be 50 or 60 Hz. Compression applications will range from high-pressure, high-ratio conditions to high-flow, low-ratio conditions. A wide range of pre-engineered options would be necessary.

- **Compliance with industry standards and expectations.** The industry tends to rely on standards from ASME, API, NEC, and other organizations to define acceptable practices for design, manufacture, and testing of gas turbines. Compliance with these standards would facilitate customer acceptance of an all-new design. In addition, the selection of recognized high-quality suppliers of components for instrumentation and auxiliary systems would minimize the risk of new product development.

These were the primary product goals, from which the product design process was to be derived. It was evident that the design process required the input of a wide variety of disciplines, some of which were more business-process than product-oriented. One last constraint was placed on the decision - it was agreed that the first production unit would be designed, assembled, and ready for testing in an overall period of only eleven months. This would be an ambitious cycle time for the build of a large gas turbine package to an existing design, much less the creation of an all-new design along the way. It was clear that the design would have to proceed on several fronts concurrently in order to meet this schedule.

### THE DESIGN PROCESS

**Organization**

In the past, this design effort would have been done in a series of sequential steps, with tasks moving from one department to the next according to the technical specialty required. The pitfalls inherent in this bureaucratic system are well-known by now. The question at hand was not whether to take a more modern approach, but how to organize it. The stakeholders in this process, those parties who were involved in inputs to or outputs from the design effort, would need to share in the process in as timely a manner as possible. A matrix organization composed of representatives from a wide cross-section of company functions was developed to form the core project team (See Chart No. 1). Members of this team would report functionally to a dedicated Program Manager. They would collaborate on a series of design tasks internal to the team. In addition, they coordinated design tasks being done concurrently by parties outside the company.

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**Chart No. 1 - Matrix Organization Structure**
**Internal Design Tasks**

The design efforts undertaken directly by the team members included the package layout and mechanical systems design, compressor design, control system design, and design of a selection of pre-engineered standard options.

The lead on package layout and mechanical systems design was taken by the Supervisor from the Engineering Standards department, who had previous experience with package design as well as with creation of the standards used by other designers. This selection was made in part because the package design was to be incorporated as a baseline product definition; a standard product which would be offered with a variety of options but which would not require significant custom engineering for each application. This lead engineer worked closely with the CAD Drafter/Designer to develop the layouts that would be the basis of the detailed assembly and part drawings.

It had been identified early on that the existing line of centrifugal compressors was inadequate to fully cover the range of applications that would be available to the new turbine driver. Development of a comprehensive product range would require design enhancements to three existing compressor models, and creation of two all-new models. The compressor design task was headed by the Team Leader from the Compressor Research and Development department. A group was created that would work exclusively on compressors to support the CES/Allison program, unhindered by demands from other business activities.

A dedicated Controls Engineer was chosen from the CES En-Tronic Controls. This individual worked with his counterparts at Allison as well as with the lead package designer to establish the system requirements and provide a suitable design for what would be an all-new (for CES) approach to location of the control panel.

With input from the Marketing department, a list of required pre-engineered options was developed. Designs for these items would be needed at the start of the product marketing effort, in order to enable offering of the short delivery times that were seen as necessary to be competitive. The lead on this effort was also assigned to a Standards Engineer, dedicated to the project.

These four design efforts were closely intertwined. In addition, they all required input from departments other than those of the lead engineers. In order to facilitate the exchange of information, the complete team (as defined in Chart No. 1) met weekly to review progress and share any information of interest. These meetings frequently uncovered potential problems that might otherwise have gone unrecognized. As each team member described his previous week’s activities, questions were raised and solutions volunteered. The meetings also were valuable in a less specific but equally important way. By promoting individual participation and team identity, the meetings helped to improve inter-departmental working relationships. A sense of mission was instilled by members of upper management, who made it clear that the team’s success was of strategic importance to the company’s broader goals.

**External Design Tasks**

In addition to managing their internal tasks, the team coordinated the efforts of several external groups who worked concurrently. These efforts included the power turbine design by the Allison project engineering team, an independent design audit contracted to an outside party, a design review by a group of representatives from users of similar turbomachinery, and the designs of major purchased components by CES’ alliance partner suppliers.

The design of the S01-KC5 power turbine by Allison was not complete at the time the package design was initiated, and the two efforts were completed at about the same time. Since the power turbine design had a significant impact on the package layout and detailing of the on-skid auxiliary systems, it was necessary for the CES and Allison teams to coordinate closely, sharing working level information as it became available. Monthly design review meetings were held between the two parties, to steer the progress from a management level.

CES contracted with an outside engineering firm to audit the auxiliary systems designs and to perform a structural analysis of the baseplate designs. These reviews began with preliminary drawings and schematics, as there was not time to complete all the details before the audit had to begin. This meant that close communication with the outside firm was necessary throughout the audit, to agree details and to incorporate changes that were suggested. This approach was successful, by achieving the benefits of an independent review with minimal impact on the overall design cycle time.

Once the design effort had proceeded to the stage that layout drawings, systems schematics, and isometric computer models were available, representatives from gas & oil industry users of gas turbine equipment were invited to review and critique them. Nine representatives from seven companies attended this session. They had supervisory and management-level backgrounds in operations, maintenance, and engineering. The session proved to be highly valuable in identifying the needs and preferences of this industry group, and resulted in some changes to the package layout.

CES works with a core group of alliance partner suppliers for the specification of certain major outsourced components, including inlet air filtration systems, couplings, fire & gas detection and suppression systems, and acoustic enclosures. These alliance partners contribute substantial design effort to their portions of the overall package. They review the package layout at the earliest stages, and make suggestions that result in design improvements and cost savings for both parties. These concurrent design efforts meant additional coordination requirements for the project team.

The design process resulted not only in the creation of product features, but revised business practices as well, which enabled the product goals to be met.

**PRODUCT FEATURES**

**Package layout**

The turbine/compressor package is designed to be as fully self-contained as possible. The power skid and compressor skid will be fabricated separately, then joined at the factory to form a single unit that is tested and shipped as one piece (See Figure 1). Items located within the baseplates include:

- The engine/compressor lube system, complete except for the cooler.
- The fuel gas system.
- The start system, either gas-expansion or electro-hydraulic.
- The control system, including microprocessor-based controller with man-machine interface and all required sensing devices.
- The fire & gas detection/protection system, with dedicated controller and CO2 distribution system, when an acoustic enclosure is specified.
- The acoustic enclosure.
Figure No. 1 - Gas Turbine Package Layout
The controller is suitable for Class 1, Group D, Division 2 environments and, with purging of the cabinet, for Division 1 areas. This arrangement simplifies on-skid wiring. Most switches and transmitters can be located near the control cabinet, eliminating the need for long conduit runs and numerous junction boxes. All control system wiring is tested at the factory, and remains intact during shipment. The installation and testing of expensive interconnecting wiring at site is not required. CRT display, data acquisition and trend monitoring are accomplished by an optional remote-mounted system which requires only a simple coaxial wire connection to the equipment skid.

**Standard options**

While the goal of reduced cycle time drives a strategy of product standardization, the goal of wide flexibility of application works in the opposite direction - toward having designs customized for each project. The logical compromise is to have a variety of pre-engineered options available which can be selected to tailor the equipment package for each application. By having these options designed in advance and, in some cases, available as pre-assembled modules, a potential user can fit the equipment to his specific needs without jeopardizing the delivery lead time. Options which are available for the CR501-KC5 include:

- Acoustic enclosure, with vent system, and fire & gas detection / protection.
- DLE and dual fuel systems
- Self-cleaning, multi-stage, and marine-style inlet air filters.
- Remote-mounted control system.
- Electro-hydraulic and air-expansion start systems.
- Remote-mounted CRT display and data acquisition / trend monitoring system.
- Inlet and exhaust plenum orientation 45° to either side, for reduced unit height in indoor applications.
- Materials selections for offshore, corrosive environments.
- Ancillary skid for mounting on top of the enclosure, with pre-assembled inlet air filter, enclosure vent system, lube oil cooler, and exhaust system.

Other options will be added as needs for them are identified.

**Compressor Development**

The gas turbine driver is of no use by itself. In compression applications, the gas compressor must be matched to the driver and must be available at the same time. Centrifugal compressors for larger turbines typically take longer than the 6-9 months lead time that was seen as being necessary to be competitive in the smaller horsepower market. Aero components are custom-designed for each application. In the larger compressor lines, rough stock for these components is not placed on order until the design is complete. For the Cooper / Allison compressor sets standard families of aero component rough stock, suitable to support any custom design, will be placed in inventory. Compressor cases and shafts

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**Modular construction**

Major subsystems are designed to be preassembled in modules. Manufacturing lead times can be reduced if pre-tested modules are available off the shelf to be installed in the baseplate. Modules for the lube oil, fuel gas, seal gas, start gas, and post-cooling oil systems have been designed.

**Lube oil system**

The gas generator, power turbine, and driven equipment are fed synthetic oil by a common oil system with its reservoir integral to the turbine baseplate (See Figure 2). The main lube oil pump is shaft-driven from the power turbine auxiliary drive. All piping is 316 stainless steel, eliminating the need for pickling and painting. Starting is supported by an A.C. motor-driven auxiliary pump. Post-cooling of the power turbine after shutdown is via an overhead rundown tank or pneumatic motor-driven pump. When an oil-to-air heat exchanger is specified, it will be shipped loose for installation at site or can be mounted on an auxiliary skid atop the enclosure.

Use of a common lube oil system for all items of equipment simplifies the overall package and eliminates the expense of having two separate systems.

**Fuel and starting gas systems**

Whether a standard or DLE combustion system is specified, the electrically actuated fuel metering valve(s), as well as all required shut-off and vent valving and piping, are included within the baseplate (See Figure 3). The standard gas-expansion starter motor is mounted to the gas generator starter drive pad. Gas for the starter is taken off the fuel gas system within the skid, so only one external gas connection is required. All necessary starter gas regulation, control valving, relief valving, and piping are provided within the skid.

**Control system**

In a departure from previous gas turbine package designs, a stand-alone control system is mounted on the gas turbine baseplate. The functions performed by this microprocessor-based system include:

- Engine, compressor, and yard valve sequencing
- Temperature and vibration monitoring
- Fuel governing
- Unit status display
- Compressor anti-surge control

The compressor seal gas system, when dry gas seals are specified.

These systems are all located on the equipment skid, pre-piped and wired. This will result in better quality assurance, because there is almost no disassembly for shipment or subsequent reassembly at site. The cost and time required for installation and commissioning will be dramatically reduced. For simplicity of station design, all piping interfaces are located on the same side of the skid.

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Figure No. 3 - Fuel Gas System
will also be standardized and kept on hand. Aero designs will still be custom-engineered for optimum efficiency, but the overall compressor lead time can be reduced to match that of the gas turbine driver.

Having produced a wide range of both multistage barrel and pipeline-style compressors since the 1950's, CES already had three families of compressors suitable for application with Allison turbines. A development program was put in place to produce the standard rough stock definitions that would allow inventory of material. In addition, work was begun on two new high-efficiency axial-inlet pipeline compressor designs, modeled after existing larger versions.

REDESIGNING THE BUSINESS

Taken alone, the product features mentioned above would not result in attaining the goals set for the program if they were to be produced using the business practices employed for the larger, custom-engineered turbine line. Changes to procedures, organizational structures, and facilities have been put in place which will result in a “business within a business”, run in a significantly different manner. These changes affect almost every part of the company.

Sales and Marketing

If the equipment offered is relatively standardized, then the proposals which describe the equipment can be standardized as well. This reduces the degree to which new material must be generated for each proposal. While preparation of new proposal material is done in the central Marketing office, tailoring of a standard proposal and submitting it to the potential customer can be decentralized to the field Sales offices. This will greatly reduce response time, permitting better service to the buyer.

Project / Standards Engineering

With the larger Cobrra® line of turbines, a great deal of engineering begins after receipt of a purchase order. The package is designed to comply with customer specifications, which are usually quite detailed. Procurement of some critical items cannot proceed for a period of months, until this engineering is completed and approved. If a standard package can be sold, engineering lead times can be drastically reduced and more critical items can be kept in inventory. This reduces both cycle time and cost. The overall engineering effort is still substantial, but the focus shifts from contract-specific design to design of standard options. Instead of starting after receipt of order, the engineering must be done in advance.

Material Control

The large turbine line is strictly built-to-order. Whether built in-house or purchased outside, all materials are associated with a unique SO, or shop order number, which ties them to a specific customer and project. With the Cooper / Allison turbines the opposite approach will be taken, with units built to the sales forecast and inventory accumulated independently of order placements. This required several revisions to the procedures used for inventory management.

Assembly / Test

By building inventory to a forecast, it is hoped that the workload in the factory can be leveled somewhat, even though order receipt may tend to be cyclical. Product standardization means that the work done will be repetitive, which in turn means that productivity should increase after an initial learning curve is traversed. Assembly and test of the Cooper / Allison units will be in an area isolated from the Cobrra® facility, in order to optimize procedures and work rules for this different philosophy.

SUMMARY

The opportunity to introduce an all-new aeroderivative industrial gas turbine package to the oil & gas market has resulted in not only a product design effort for the manufacturer, but a chance to rethink the design process itself. As a result the new product incorporates the advantages of changes to the manufacturer’s procedures, organization, and facilities as well as several innovative mechanical design features.