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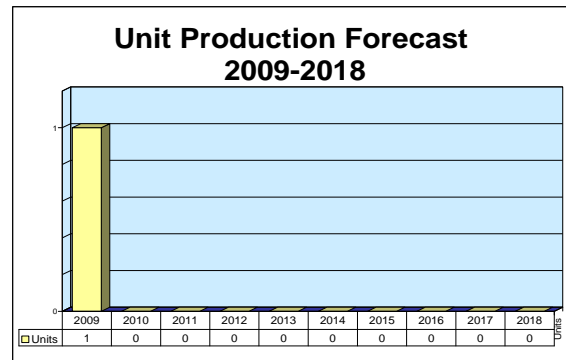
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Rolls-Royce Industrial Avon

Outlook

- Production expected to end in the forecast period, yielding to newer-technology machines; a few more years of orders are projected for mechanical drive
- Major competition to the Avon is the Solar Titan 130, followed by the Mitsubishi MF-111B



Orientation

Description. The Industrial Avon is a single-shaft, open-cycle, axial-flow, aero-derivative industrial gas generator for 50-Hz/60-Hz mechanical drive and electrical generation.

Sponsor. The aviation Avon engine was developed in the early 1950s by the prime contractor, with sponsorship by the U.K. government.

Power Class. The approximate power output of the Avon mechanical drive package is 20,360-21,000 bhp for mechanical drive and 14.6-15.1 MWe for electrical generation.

Status. The Industrial Avon is in low-level production.

Total Produced. At the start of 2009, an estimated 1,200 Industrial Avon gas generators and gas turbine machines had been built and installed worldwide.

Application. The main applications are mechanical load drive duty (pipeline and process industry) and utility and industrial power generation, including cogeneration.

Price Range. \$4.8-\$5.1 million for mechanical drive applications; \$5.9-\$6.3 million for power generation applications (estimated in 2009 U.S. dollars).

For electrical generation (simple-cycle), the genset price covers a single-fuel skid-mounted gas turbine, electric generator, air intake with basic filter and silencer, exhaust stack, basic starter and controls, and conventional combustion system.

For mechanical drive, the price covers a gas-fired gas turbine (without driven equipment) with gearbox, skid, enclosure, inlet and exhaust ducts, and exhaust silencer; basic turbine controls; fire protection; starting systems; and conventional combustion system.

Competition. In the mechanical load drive arena, the gas turbine machine that most actively competes against the Industrial Avon is the Solar Titan 130. Other competitors include the Zorya-Mashproekt UGT-16000 and the GE Energy LM1600.

In the electrical generation arena, the chief competition comes from the Solar Titan 130 and the Mitsubishi MF-111B. Other competing machines are the GE Energy LM1600, the Iskra Energetika GTES-16 (PMZ GTU-16P), and the Zorya-Mashproekt UGT-10,000 STIG.

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Contractors

Prime

Rolls-Royce plc	http://www.rolls-royce.com , 65 Buckingham Gate, London, SW1E 6AT United Kingdom, Tel: + 44 20 7222 9020, Fax: + 44 20 7227 9178, Prime
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Subcontractor

Altair Filters International Ltd	http://www.altairfilter.com , Omega Park, Alton, GU34 2QE Hants, United Kingdom, Tel: + 44 1420 541188, Fax: + 44 1420 541298, Email: info@altairfilter.com (Acoustic Equipment)
British Filters Ltd	Thames Industrial Estate, Fieldhouse Ln, Marlow, SL7 1TD United Kingdom, Tel: + 44 06284 73131 (Engine Fuel Filter)
Chromalloy France	http://www.chromalloy.fr , Ave des Gros-Chevaux, Z.I. du Vert Galant, St.-Ouen-L'aumone, 95310 France, Tel: + 33 1 3440 3636, Fax: + 33 1 3421 9737, Email: info@chromalloy.fr (HP Blade)
Environmental Elements Corp	http://www.eec1.com , 3700 Koppers St, Baltimore, MD 21227 United States, Tel: + 1 (410) 368-7000, Fax: + 1 (410) 333-4331 (Air Filtration & Noise Control Equipment)
GE - Aviation Systems, Actuation and Landing Gear/Power	http://www.geaviationsystems.com , 110 Algonquin Pkwy, Whippany, NJ 07981-1640 United States, Tel: + 1 (973) 428-9898, Fax: + 1 (973) 428-8532 (Governor Pump)
Hilliard Corp	http://www.hilliardcorp.com , 100 W Fourth St, Elmira, NY 14902 United States, Tel: + 1 (607) 733-7121, Fax: + 1 (607) 733-3009 (TC, TX Series Starter)
Honeywell Aerospace	http://www.honeywellaerospace.com , 1300 W Warner Rd, Tempe, AZ 85284 United States, Tel: + 1 (480) 592-5000, Fax: + 1 (480) 496-7811 (Industrial Starting System)
Howmet Castings, Corporate Machining	http://www.alcoa.com , 145 Price Rd, Winsted Industrial Park, Winsted, CT 06098 United States, Tel: + 1 (860) 379-3314, Fax: + 1 (860) 379-4239 (Investment Cast Airfoil)
PCC AETC Ltd	http://www.pccairfoils.com , Victoria Ave, Yeadon, Leeds, LS19 7AY United Kingdom, Tel: + 44 113 2505151, Fax: + 44 2113 2103006 (Machined Nozzle Vane)
Petrotech Inc	http://www.petrotechinc.com , 108 Jarrell Dr, PO Box 503, Belle Chasse, LA 70037 United States, Tel: + 1 (504) 394-5500, Fax: + 1 (504) 394-6117 (Fuel Regulator System; Fuel Valve System Upgrade; Speed & EGT Measurement & Control System)
Unison Industries, Norwich Operations	http://www.unisonindustries.com , 5345 State Hwy 12, PO Box 310, Norwich, NY 13815 United States, Tel: + 1 (607) 335-5000, Fax: + 1 (607) 335-5440 (Ignition Components)
Vosper Thornycroft (UK) Ltd	Woolston Shipyard, Victoria Rd, Woolston, SO9 5GR Southampton, United Kingdom (Control)
Wood Group Fuel Systems Ltd	http://www.woodgroup.com , Wellshead Industrial Ctr, Dyce, Unit 22, Aberdeen, AB21 7GA Scotland, United Kingdom, Tel: + 44 1224 771 133, Fax: + 44 1224 725 275 (Fuel Nozzle)
Woodward Governor Co	http://www.woodward.com , 5001 N Second St, PO Box 7001, Rockford, IL 61125-7001 United States, Tel: + 1 (815) 877-7441, Fax: + 1 (815) 639-6033 (Industrial Control)

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Rolls-Royce Industrial Avon

Technical Data

Design Features

Intake. Annular intake with bulletdome spinner. A compressor bleed air anti-icing system for nose fairing and intake is standard. Filtration and silencing ducts are available as required.

Compressor. Single spool with 17 axial stages of diminishing diameter. A single stage of variable inlet guide vanes and two automatic bleed valves optimize compressor performance across the full range of gas generator speeds. Gas compressor ratio is 8.8:1. Stage 1 blade is made of titanium; Stage 1 stator blades are of stainless steel. Stages 2-4 stator blades are aluminum; blades for Stages 7-17 are stainless steel. Discs are corrosion-resistant steel. Variable inlet guide vanes. Casing is aluminum.

Combustor. Eight interconnected straight-flow combustors contained within an outer casing (termed turbo-annular by Rolls-Royce). Later-model Avons use an improved combustion system with a ceramic-coated Nimonic 263 liner to allow greater heat. Casing is cast from medium-carbon steel.

Turbine. A three-stage axial turbine drives the single compressor spool. The standard Avon has cooled X40

alloy. The later Avons feature additional cooling of the rotor blades and improved stator cooling. The most recent Avons have full cooling, plus improved materials in the turbine. They use cast IN738 blades for Stage 1 and forged Nimonic 115 blades for Stages 2-3.

Bearings. Anti-friction ball and roller bearings are standard. The front and rear radial bearings are single-row roller bearings. The center thrust bearing is a single-row ball type.

Control System. Avon machines are fitted with a closed-loop electronic governor system, known as a unified system. The governor monitors parameters and meters fuel flow to the gas generator to control automatic startup, sequencing and loading, operation, and shutdown.

Accessories. Starting is normally accomplished via a 110-volt DC motor, but alternative systems are offered. The lubrication oil system contains filters and a chip detector. Some packagers provide their own integrated oil system, which provides for the needs of both the gas turbine and the free power turbine.

Dimensions. The approximate dimensions and weights of the Avon 2648 and Avon 2656 mechanical drive packages are as follows (packages include Industrial Avon gas generators plus two-stage heavy-duty power turbines):

	<u>Metric Units</u>	<u>English Units</u>
Length	6.4 m	21.0 ft
Width	3.04 m	10.0 ft
Height	3.04 m	10.0 ft
Weight, overall		
Avon 2648	22,680 kg	50,000 lb
Avon 2656	23,580 kg	52,000 lb
Weight, overall (GG & GT)		
Avon 2648	15,875 kg	35,000 lb
Avon 2656	17,237 kg	38,000 lb

Performance. The Avon 2648 and Avon 2656 mechanical drive and electrical generation packages have the following performance parameters:

	<u>ISO Power</u>	<u>Power Turbine Speed</u>	<u>Fuel Rate</u>	<u>Thermal Efficiency</u>	<u>Exhaust Mass Flow</u>	<u>Stack Temp</u>
Mechanical Drive						
Avon 2648/2648 DLE	20,360 bhp	5,500 rpm	8,660 Btu/hp-hr	29.4%	77 kg/sec	442°C
Avon 2656/2656 DLE	21,000 bhp	4,950 rpm	8,405 Btu/hp-hr	30.3%	77 kg/sec	437°C
Electrical Generation						
Avon 2648	14,672 kWe	5,500 rpm	12,686 kJ/kWh	28.4%	77 kg/sec	442°C
Avon 2656	15,131 kWe	4,950 rpm	12,313 kJ/kWh	29.2%	77 kg/sec	437°C

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Variants/Upgrades

At the present time, there are two basic Avon model groups:

Coberra 2648. The Coberra 2648 combines an Avon industrial gas generator with a Cooper-Bessemer RT48 power turbine.

Coberra 2656. The Coberra 2656 combines an Avon industrial gas generator with a Cooper-Bessemer RT56 power turbine.

Note: *DLE combustion technology is available as an option for new Avon units, as well as a retrofit for existing packages.*



Rolls-Royce Avon

Source: Rolls-Royce

Program Review

Background. The Rolls-Royce Industrial Avon is a simple-cycle, single-shaft gas turbine generator from the well-known aviation series of Avon turbojet engines.

Initial production of the Avon for aviation began in the early 1950s, and the engine was subsequently used aboard a large number of civil and military aircraft, including the Comet and Caravelle transports, BAE Lightning and Canberra, and Saab Draken. Development of industrialized versions began in the early 1960s and has since replaced the aviation engine as the sole Avon variant in production.

The first industrial application was the installation in 1963 of a single Avon in a Cooper-Bessemer compression package for Trans-Canada's pipeline system. The first Avon-powered electrical generating set was installed in 1964 for the Central Electricity Generating Board by the Gas Turbine Division of English Electric, which was later incorporated into GEC-Alsthom.

Avons are traditionally sold as gas generators to be mated with power turbines and driven equipment supplied by packagers. The installed units have

accumulated over 53 million hours of operating experience, with many units having achieved over 120,000 hours of operation; the fleet's leading engine has exceeded 160,000 hours.

Since its introduction in the early 1960s, the Avon gas generator has been progressively uprated and improved from its 12,500-horsepower rating to the most recent Avon 2656 ratings of 15.66 MW and 21,000 horsepower. According to the Rolls-Royce, the Avon is currently the least expensive machine in its power class, and has an excellent reliability record and low maintenance costs. These factors contribute to continued moderate sales of the turbine.

In order to comply with the new worldwide emissions standards, Rolls-Royce has sought to reduce CO levels, as well as NOx levels (with water injection), to retain the engine's marketability.

The Industrial Avon machines are manufactured and assembled by Rolls-Royce in Montreal, Quebec, Canada.

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A dry low emissions (DLE) version of the Avon was introduced around 1997, offering, in comparison to conventional gas turbines, about a 20 percent power increase while cutting NO_x and CO emissions by 50 percent compared. The first installation on the pipeline operated and owned by the U.K.-based company Transco, involving two Coberra Avon 2656 turbines used to compress natural gas, can generate annual reductions of about 170 tons of NO_x and 100 tons of CO.

The DLE combustion system is based on technology similar to that used on the larger RB211 and Trent. The DLE is a fuel-staged combustion system that uses premix lean-burn technology. The mixing of air and fuel is strictly controlled to minimize NO_x and CO formation. It also stabilizes combustion over the operating range. The Rolls version does not require bleeding compressor air to provide good operability. Emissions performance is equally good at both part- or full-load operation.

The DLE can be retrofitted on existing engines, in addition to being specified for new builds.

Packagers Galore

The Industrial Avon is usually supplied as a completely packaged gas turbine driver; the unit is designated the Coberra 2000. The two-stage heavy-duty power turbine was previously supplied by Cooper Rolls Inc, Mount Vernon, Ohio. That entity is now part of Rolls-Royce Energy Systems Inc, Mount Vernon.

Several Industrial Avon packagers have incorporated the machine into product lines, as follows:

Cooper Rolls. Cooper Energy Services (CES) and Rolls-Royce have a long history of cooperative efforts in the industrial market, coupling R-R gas generators with CES-driven equipment. The long affiliation was strengthened with the formation of Cooper Rolls Inc (CR), a jointly owned company formed by both firms. CR produced, marketed, and serviced the Coberra series of R-R-packaged systems for industrial applications using the Avon and RB211 gas generators.

The two-stage RT48 is the power turbine component of the Avon-based Coberra 2000. The RT48 entered service in 1960 with an expansion efficiency of 82 percent. Its current efficiency was attained in the mid-1980s. Rotor blades and stator vanes are precision cast in a nickel-based alloy. The turbine rotor shaft is a one-piece forged alloy steel construction. It is supported within a bearing case by tilting pad journal bearings. The thrust bearing is self-leveling.

Both Cooper Rolls and Rolls-Royce have been active worldwide with the Avon in mechanical drive applications, particularly in the North Sea fields, the Middle East, North America, and South America. Sales were also made to customers for installation in the South China Sea; that and the surrounding region continue to hold potential for the exploration and exploitation of major petroleum and gas deposits. Cooper Rolls also supplied 42 Avon-powered systems from 1978 to 1980 for the Russian Chelyabinsk pipeline.

Dresser-Rand Company. This firm, through its Turbo Products Division, has offered the Rolls-Royce Avon gas generator in its GT54, rated at 21,000 horse-power.

Note: *Dresser-Rand no longer packages the Avon turbine, concentrating instead on GE LM series machines.*

Dresser-Rand A/S (formerly Kongsberg Dresser Power). Avons were made available from this joint venture firm under such designations as DJ-170G, DJ-160R, and DJ-200R. The last known offering was designated the GT54, with a rating of 15 MW.

Note: *Dresser-Rand A/S no longer packages the Avon turbine.*

GEC Rolls-Royce (Power Generation) Ltd. GEC, which in 1983 reorganized its gas turbine operations to include marketing and support of Ruston gas turbines, offered the total range of Avon systems, including single, twin, and quadruple gas generator arrangements. Although GEC packaged modern aeroderivatives from Rolls-Royce and GE, the great majority of engine drive systems were powered by the Avon. Over 200 Avon-powered EAS-1 series systems were placed into operation.

Note: *All in-service EAS-1s are maintained by Rolls-Royce plc.*

Sulzer-Escher Wyss Ltd. In addition to three indigenous designs, Sulzer also took the Rolls-Royce series into its product line with the now-canceled Primo series. The series consisted of the Avon-powered Primo 12, 14, and 15, and the Primo 21 with an RB211. Sulzer's first sale was to Rolls-Royce for a Primo 14 compression unit at Derby, U.K., and two Primo 14 generation sets were sold to Libya in 1981. Four Primo 14s went on line in Riyadh, Saudi Arabia, in 1982. While the Primo series was expected to expand Sulzer's potential, sales were slow in materializing, and Sulzer discontinued the line in 1986.

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In December 2000, the divestiture of Sulzer Turbo AG from Sulzer Ltd to the MAN Group was announced.

The change of ownership was completed in May 2001. The turbomachinery activities of the MAN Group are operated under the brand name MAN TURBO.

Early Packagers. Early packagers of Industrial Avon machines included BBC, IHI, MAN, Stal Laval, Westinghouse Canada, and Worthington.

Funding

No recent U.K. or U.S. government funding for the Rolls-Royce Industrial Avon gas turbine machine has been identified.

Contracts/Orders & Options

No major contracts pertaining to the Rolls-Royce Industrial Avon gas turbine machine have been awarded or announced in the recent past.

Timetable

<u>Month</u>	<u>Year</u>	<u>Major Development</u>	
Oct	1962	First Industrial Avon ordered	
	1963	First Avon begins commercial operation	
	1964	First gas pumping installation, at TransCanada Pipelines' site at Caron in the U.K.	
	1964	First electrical generation installation, at (then) CEGB's site at Earley in the U.K.	
	1969	First offshore installation, at Lake Maracaibo, Venezuela	
	1970	Maxi Avon available	
	1971	Dual-fuel capability introduced	
	1975	Super Maxi Avon available	
	Mid-Sep	1975	First Avons go on-line in North Sea for oil service
		1975	First Avons go on-line in Trans-Alaska Pipeline operation
1978		First of 42 Avons begin pumping duty in the USSR	
1983		The 42 Avons in Russia exceed one million operating hours	
1984		1,000th Avon sold to ONGC in India	
Jun	1984	Mk 1535 announced	
	1986	Sulzer discontinues Primo offering	
	1989	DLE Combustion System program begun	
	1997	Two Coberra 2000 units sold for installation in Russia's Tomsk region	
Oct	1998	Three Coberra 2000 units sold for installation in a Venezuela gas field	
	1998	Two DLE compressor drivers become operational in the U.K.	
End	1999	Rolls-Royce fully acquires Cooper-Rolls, which is melded into Rolls-Royce	
Aug	2003	PTT orders two follow-on Avon electrical generator sets	
Into	2008	Continued production of Industrial Avon	
Thru	2018	Continued aftermarket support of in-field Avon machines	

Worldwide Distribution/Inventories

At the start of 2009, an estimated 1,200 Industrial Avon gas turbine machines had been installed in 39 countries and territories worldwide.

Forecast International's Industrial & Marine Gas Turbine Installations Database includes 1,101 Avon machines, as follows:

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- Avon (Generation): 312 machines installed in 29 countries.
- Avon (Mechanical Drive): 789 machines installed in 29 countries.

The major customer nations are **Canada** (69 machines), **Germany** (51), **Iran** (94), the **Netherlands** (23), **Russia** (99), **Saudi Arabia** (24), **UAE** (69), the **U.K.** (294), and the **U.S.** (167).

Forecast Rationale

While the Industrial Avon gas turbine machine remains in operation in Asia, Europe, and the Middle East, sales of new-build machines have been few and far between in the past few years.

The few machines that are projected to be ordered in the current period should be for mechanical drive applications. We believe that the machine will remain production-ready for use in the power generation arena, especially since the dry low emissions (DLE) combustion system has extended the life of these machines. By the end of the forecast period, newer and

more efficient gas turbine models will have replaced the venerable Avon, even with DLE.

With the worldwide electrical generation and mechanical drive markets becoming more robust, our forecast calls for only a few more years of production of the Industrial Avon turbine, with one machine expected to be produced over the forecast period.

At this point we believe that the Avon will end its normal production life cycle in 2009, after which it will be available only on a special-order basis.

Ten-Year Outlook

ESTIMATED CALENDAR YEAR UNIT PRODUCTION												
Designation or Program	High Confidence					Good Confidence			Speculative			Total
	Thru 2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
Rolls-Royce plc												
Industrial Avon <> SHP =>20,000 <> Mechanical Drive (Pumps & Compressors)												
	824	1	0	0	0	0	0	0	0	0	0	1
Total	824	1	0	0	0	0	0	0	0	0	0	1