



Multi-Stage Centrifugal Compressors

THE WORLD TURNS TO ELLIOTT

Our History - Over 100 Years of Innovation and Success

Since 1910, Elliott has provided innovative solutions, unmatched expertise, and first-class service to the global turbomachinery marketplace worldwide. Elliott designed, tested, and installed some of the industry's most rugged and dependable equipment. In fact, some Elliott compressors and turbines installed in the 1940s and 1950s are still in operation today, either as originally supplied or upgraded to handle new process conditions or more stringent environmental standards.

We have been on the cutting edge of technological advancement throughout our history, consistently providing advanced technology in aerodynamics, rotor dynamics, process simulation, and metallurgy. Our customers have benefited from our state-of-the-art production innovations, which continue today, including fabricated casing technology, high-pressure casing technology, and impeller welding techniques.

In the mid-1990s, Elliott launched the EDGE™ development program to improve the performance of our multi-stage centrifugal compressor line with the latest in aerodynamic technologies, while reducing cost and cutting lead time to supply a machine in half – from 10 to 12 months to as low as 6 months. The first EDGE compressors were built for Shell in 1998, and Elliott's current scalable compressor designs are based upon EDGE technology.

We know that change is essential in achieving and maintaining a competitive edge in today's worldwide business market. Together with our customers and suppliers, we continue to innovate, improve, and expand our extensive portfolio of products and services that serve the energy industries. We work with our customers to provide custom applications, as needed, to meet their specific project needs.



■ WHAT WE OFFER - ADVANCED COMPRESSOR TECHNOLOGY

Superior Performance

Through our various development programs, we combine our comprehensive knowledge of turbomachinery with the latest design software, manufacturing processes, and machine tools. As a result, Elliott's multi-stage centrifugal compressors lead the industry in both performance and reliability.

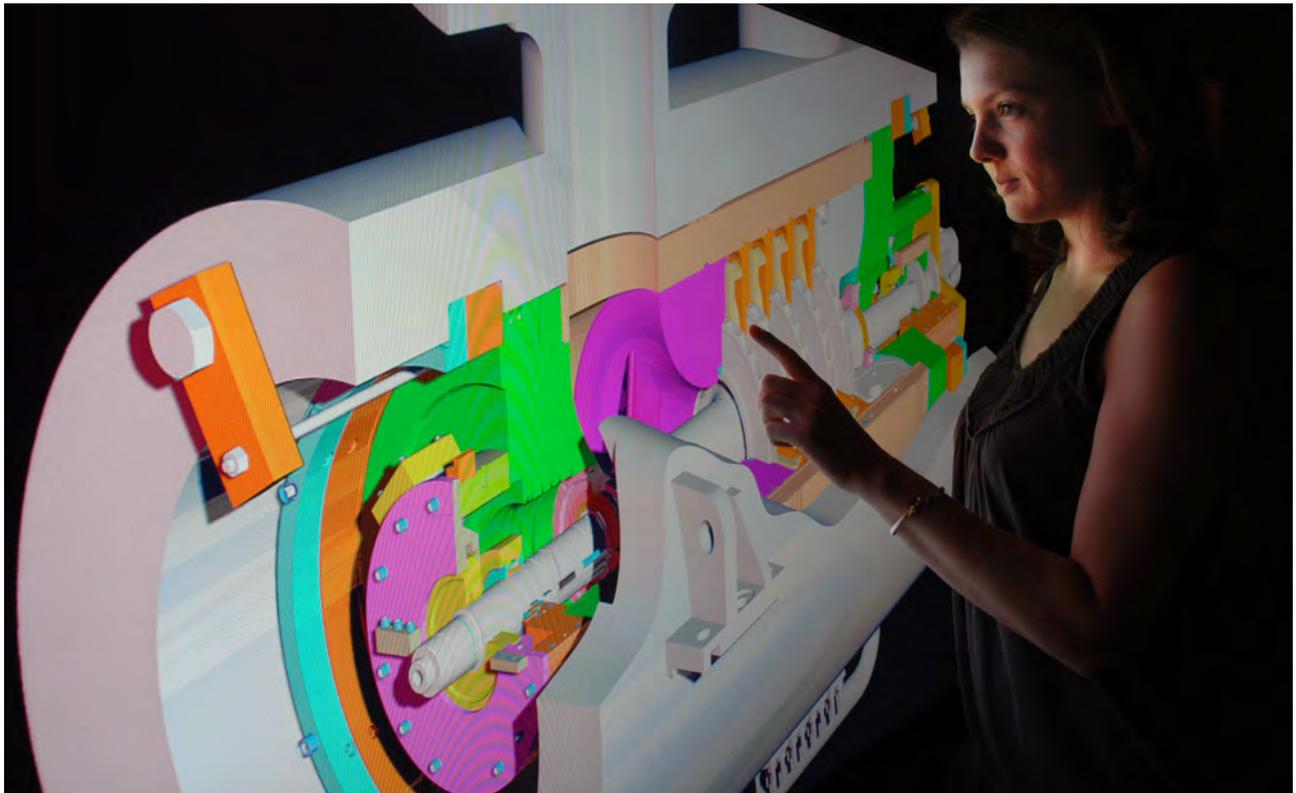
Increased Aerodynamic Efficiency

Elliott uses state-of-the-art interactive design and prediction tools to optimize aerodynamic performance and increase flange-to-flange efficiencies. We develop compressor impeller and matched stationary flowpath components using computational fluid dynamics (CFD) analyses and dynamic simulations. We optimize three-dimensional blade profiles, diffuser flow angles, crossover bend curvature, area ratio, and return channel vane shapes for each impeller stage to provide the best possible efficiency. To achieve additional performance enhancements, we improve the flow distribution channels at the inlet and discharge volutes and sidestream mixing areas. These enhancements allow us to provide some of the industry's highest operational efficiencies.



Improved Rotor Stability Characteristics

Through extensive research in the fields of rotor-dynamic stability, aerodynamic cross-coupling stiffness, and rotor-bearing systems, we have developed proprietary analytical tools. Incorporating these developments into Elliott compressor designs has produced a number of product enhancements. For example, we increased rotor stiffness by increasing shaft diameter, reducing impeller weight, and increasing journal bearing sizes. This allows higher torque transmission capabilities and higher-speed operation, with improved rotor stability characteristics, which are essential as gas densities and operating pressures increase.



■ CASING FEATURES

Elliott's compressor casing design reduces the required manufacturing steps and simplifies field assembly. To achieve higher operating pressures, we applied state-of-the-art solids modeling and finite element analysis techniques.

Small and mid-sized horizontally split casing sections are made from a single piece of rolled steel plate with horizontal flanges that are machined—not welded—into the side. Cast steel casings are used for some applications. High-strength casing through-bolts provide superior clamping forces. Endwalls are made from a single solid plate. The resulting casing has fewer sealing surfaces, is easier to manufacture and assemble, and has increased pressure capabilities compared to conventional designs. Larger horizontally split casings have rolled barrel sections with welded-on endplates and welded-on horizontal flanges.

Vertically split MB-line compressors feature a complete inner casing assembly. This includes a horizontally split inner casing with diaphragms, stationary seals, rotating elements, bolted-on endwalls, and shaft end seals. This module can be inserted or removed from the outer casing as a single piece, which simplifies compressor assembly and reduces turn-around times.

We typically use milled flats for **Society of Automotive Engineers (SAE)** flanged connections, including endwall, spray nozzle, casing drain, bearing retainer, and equalizing line connections. On smaller casings where space is limited, SAE flanges provide higher ratings and more compact designs than American National Standards Institute (ANSI) flanges.

Casing Advantages

- ♦ Integral horizontal flanges on small and medium frames
- ♦ Machined flats with SAE flanges for most drain or injection connections
- ♦ Through-bolts for casing horizontal flanges
- ♦ Allowable forces and moments per API 617
- ♦ Three-dimensional solid modeling for improved design and engineering review capability
- ♦ Pro/ENGINEER® solid modeling files to enhance precision during component manufacture



■ AERODYNAMIC COMPONENTS

Elliott offers superior, three-dimensional impeller designs and stationary diaphragms. We do this by maximizing performance over a broad range of pressure and flow applications using the latest aerodynamic design and analysis technologies.

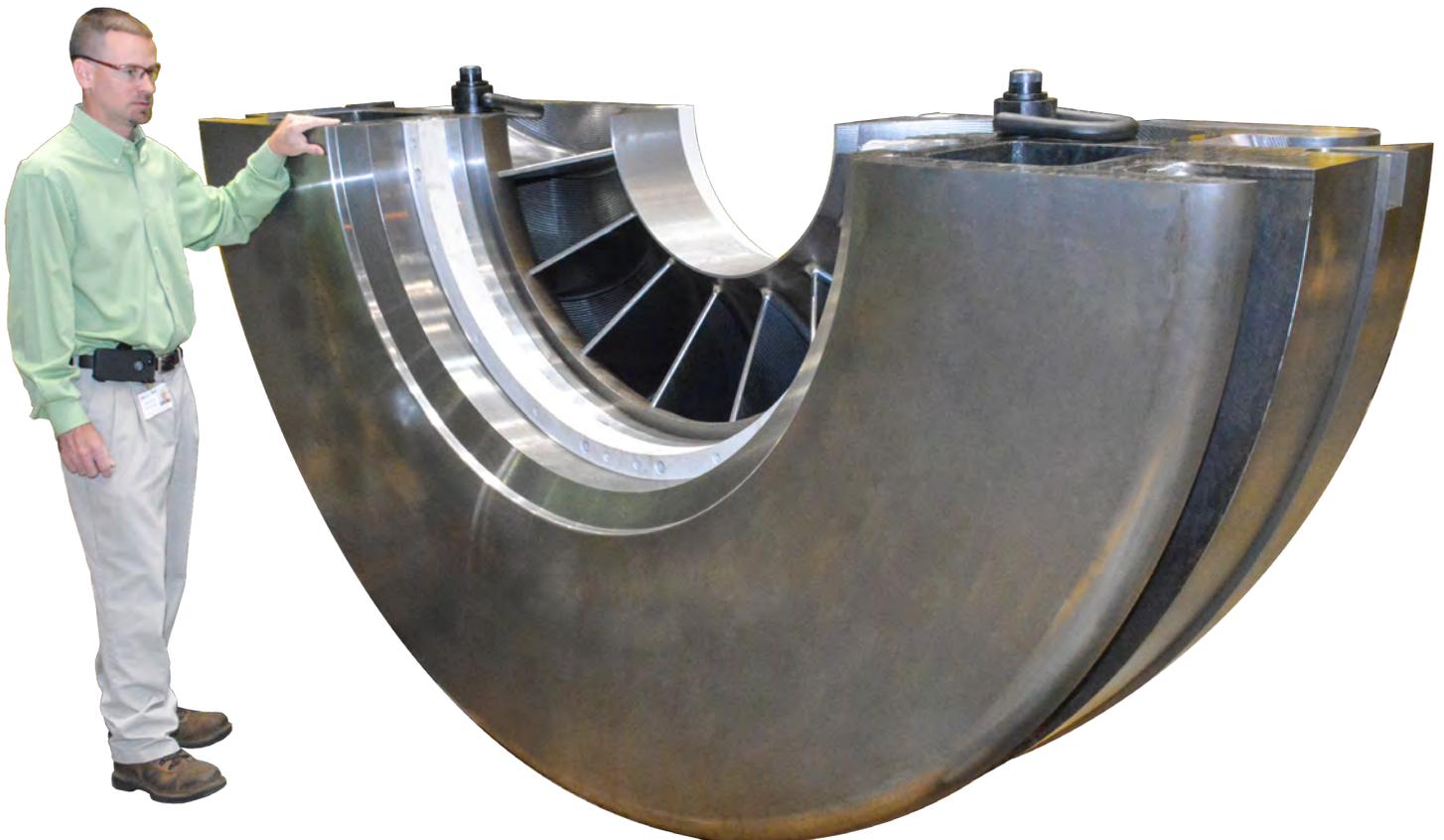
To verify predicted performance, we perform single-stage testing in various configurations, such as with vaneless or vaned diffusers, or using high or low tip Mach numbers. We derive higher and lower flow stage ratings from the prototype test data to form a “family” of stages. Within each stage family, impeller geometry is fixed; blade heights are varied for higher or lower flows.

Using this methodology, several stage families span the desired flow coefficient range. Impellers and stationary components are then scaled up or down for different frame sizes. For maximum flexibility, components are also scalable from 90 to 100 percent size within each compressor frame size.

Impeller manufacturing applies five-axis milling to ensure the quality of the advanced impeller designs. Impellers are stress relieved, machine finished, balanced statically and dynamically, spin tested, and then mounted with an interference fit onto the shaft. We use shaft-to-impeller keys for extra stability in high-pressure or high-power applications.



Our compressors use either fabricated steel diaphragms or a combination cast-and-fabricated steel design, where thickness precludes using steel plate alone. Precision machining ensures dimensional accuracy and significantly improves the diaphragm surface finish. Diaphragms are horizontally split and finished at all horizontal and peripheral joints and on gas path surfaces.



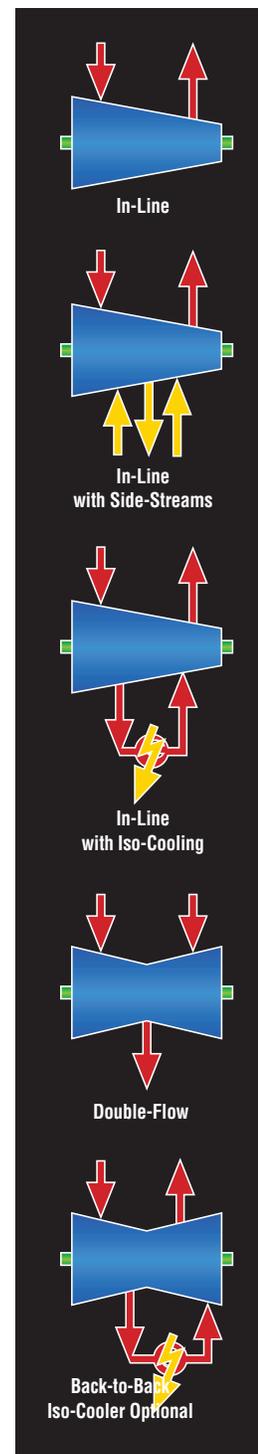
COMPRESSOR FRAME SUMMARIES

Frame	Typical Flow Range		Inlet Nozzle Sizes		Discharge Nozzle Sizes	
	m ³ /hr	CFM	mm	in	mm	in
1H – 10M ^(3,4,5) 1V – 10MB ^(3,4,5)	2,888 – 14,272	1,700 – 8,400	102, 203, 254, 305, 356 102, 203, 254, 305, 356	4, 8, 10, 12, 14 4, 8, 10, 12, 14	102, 152, 203 102, 152, 203	4, 6, 8 4, 6, 8
2H – 15M ^(3,4,5) 2V – 15MB ^(3,4,5)	3,738 – 19,029	2,200 – 11,200	152, 203, 254, 305, 356, 406 102, 152, 203, 254, 305, 356, 406, 457	6, 8, 10, 12, 14, 16 4, 6, 8, 10, 12, 14, 16, 18	102, 152, 203 102, 152, 203, 254	4, 6, 8 4, 6, 8, 10
3H – 20M ^(3,4,5) 3V – 20MB ^(3,4,5)	4,927 – 25,145	2,900 – 14,800	203, 254, 305, 356, 406, 457 152, 203, 254, 305, 356, 406, 457	8, 10, 12, 14, 16, 18 6, 8, 10, 12, 14, 16, 18	102, 203, 254 102, 152, 203, 254, 305	4, 8, 10 4, 6, 8, 10, 12
4H – 25M ^(3,4,5) 4V – 25MB ^(3,4,5)	6,626 – 33,471	3,900 – 19,700	254, 305, 356, 406, 457, 508 203, 254, 305, 356, 406, 457, 508	10, 12, 14, 16, 18, 20 8, 10, 12, 14, 16, 18, 20	152, 203, 254, 305 152, 203, 254, 305, 406	6, 8, 10, 12 6, 8, 10, 12, 16
5H – 29M ^(3,4,5) 5V – 29MB ^(3,4,5)	8,665 – 44,174	5,100 – 26,000	305, 356, 406, 457, 508, 610 203, 305, 356, 406, 457, 508, 610	12, 14, 16, 18, 20, 24 8, 12, 14, 16, 18, 20, 24	152, 203, 254, 356 152, 254, 305, 406	6, 8, 10, 14 6, 10, 12, 16
6H – 32M ^(3,4,5) 6V – 32MB ^(3,4,5)	11,553 – 58,446	6,800 – 34,400	406, 457, 508, 610, 762 305, 406, 457, 508, 610, 762	16, 18, 20, 24, 30 12, 16, 18, 20, 24, 30	203, 254, 305, 406 203, 305, 406, 508	8, 10, 12, 16 8, 12, 16, 20
7H – 38M ^(3,4,5) 7V – 38MB ^(3,4,5)	15,291 – 77,305	9,000 – 45,500	457, 508, 610, 762, 914 406, 457, 508, 610, 762, 914	18, 20, 24, 30, 36 16, 18, 20, 24, 30, 36	203, 305, 406 203, 305, 406, 508	8, 12, 16 8, 12, 16, 20
8H – 46M ^(3,4,5) 8V – 46MB ^(3,4,5)	20,218 – 102,620	11,900 – 60,400	254, 610, 762, 914 508, 610, 762, 914	10, 24, 30, 36 20, 24, 30, 36	254, 305, 406, 508 254, 305, 406, 508	10, 12, 16, 20 10, 12, 16, 20
9H – 56M ^(3,4,5) 9V – 56MB ^(3,4,5)	26,674 – 135,241	15,700 – 79,600	610, 762, 914, 1067 610, 762, 914, 1067	24, 30, 36, 42 24, 30, 36, 42	305, 508, 610, 762 305, 508, 610	12, 20, 24, 30 12, 20, 24
10H – 60M ^(3,4,5) 10H – 60MH ^(3,4,5) 10V – 60MB ^(3,4,5)	35,339 – 177,207	20,800 – 104,300	610, 762, 914, 1067, 1219 610, 762, 914, 1067, 1219 610, 914, 1067	24, 30, 36, 42, 48 24, 30, 36, 42, 48 24, 36, 42	508, 610, 762, 914 508, 610, 762, 914 508, 610, 762, 914	20, 24, 30, 36 20, 24, 30, 36 20, 24, 30, 36
11H – 70M ^(3,4,5) 11H – 70MH ^(3,4,5) 11V – 70MB ^(3,4,5)	46,723 – 235,823	27,500 – 138,800	762, 914, 1067, 1219, 1372, 1524 762, 914, 1067, 1219, 1372, 1524 762, 1067, 1219	30, 36, 42, 48, 54, 60 30, 36, 42, 48, 54, 60 30, 42, 48	406, 610, 762 406, 610, 762 406, 610, 762	16, 24, 30 16, 24, 30 16, 24, 30
12H – 78M ^(3,4,5) 12H – 78MH ^(3,4,5) 12V – 78MB ^(3,4,5)	61,844 – 314,657	36,400 – 185,200	914, 1067, 1219, 1372, 1524, 1676 914, 1067, 1219, 1372, 1524, 1676 914, 1219, 1372	36, 42, 48, 54, 60, 66 36, 42, 48, 54, 60, 66 36, 48, 54	406, 762, 914 406, 762, 914 406, 762, 914	16, 30, 36 16, 30, 36 16, 30, 36
13H – 88M ^(3,4,5) 13H – 88MH ^(3,4,5) 13V – 88MB ^(3,4,5)	81,722 – 411,840	48,100 – 242,400	1219, 1372, 1524, 1676, 1829, 1981 1219, 1372, 1524, 1676, 1829, 1981 1219, 1372, 1676	48, 54, 60, 66, 72, 78 48, 54, 60, 66, 72, 78 48, 54, 66	610, 914, 1067 610, 914, 1067 610, 762, 914, 1067	24, 36, 42 24, 36, 42 24, 30, 36, 42
14H – 103M ^(3,4,5) 14H – 103MH ^(3,4,5) 14H – 103MB ^(3,4,5)	108,057 – 541,815 108,057 – 541,815	63,600 – 318,900 63,600 – 318,900	1219, 1372, 1524, 1676, 1829, 1981, 2134, 2286 1219, 1372, 1524, 1676, 1829, 1981, 2134, 2286	48, 54, 60, 66, 72, 78, 84, 90 48, 54, 60, 66, 72, 78, 84, 90	610, 914, 1219, 1372 1219	24, 36, 48, 54 48
15H – 110M ^(3,4,5)	142,887 – 721,060	84,100 – 424,400	1372, 1524, 1676, 1829, 1981, 2134, 2286, 2591	54, 60, 66, 72, 78, 84, 90, 102	610, 1067, 1372	24, 42, 54

Notes:

1. Nominal speed is based on 900-fps mechanical speed for the 100% nominal impeller diameter for each frame size.
2. The flow ranges given for the different frame sizes are based on the nominal speed, 100% nominal impeller diameter, and flow coefficients of 0.053 on the low flow end and 0.199 on the high flow end.
3. Casing ratings for horizontally split designs do not include external volute iso-cooled units.
4. All external volutes require a splitline O-ring, unless a waiver is given by Product Engineering.
5. Refer to frame sections for “L” ratings and for “MBL” and “MBH” availability.

Casing Rating		100% Nominal Impeller Diameter		Nominal Speed	Journal Bearing Diameter	
barg	psig	mm	in	rpm	mm	in
69 138	H – 1000 V – 2000	263.550	10.376	19800	74.93	2.95
69 138	H – 1000 V – 2000	303.073	11.932	17300	74.93, 88.9, 101.6	2.95, 3.5, 4
69 138	H – 1000 V – 2000	348.539	13.722	15000	88.9, 101.6	3.5, 4
69 138	H – 1000 V – 2000	400.812	15.780	13100	88.9, 101.6, 127	3.5, 4, 5
69 138	H – 1000 V – 2000	460.934	18.147	11400	88.9, 101.6, 127	3.5, 4, 5
69 138	H – 1000 V – 2000	530.098	20.870	9900	101.6, 127, 152.4	4, 5, 6
69 138	H – 1000 V – 2000	609.600	24.000	8600	101.6, 127, 152.4, 177.8	4, 5, 6, 7
69 110	H – 1000 V – 1600	701.040	27.600	7500	127, 152.4, 177.8, 203.2	5, 6, 7, 8
55 83	H – 800 V – 1200	806.196	31.740	6500	152.4, 177.8, 203.2, 228.6	6, 7, 8, 9
41 69 69	H – 600 H – 1000 V – 1000	927.125	36.501	5600	177.8, 203.2, 228.6, 254	7, 8, 9, 10
28 52 55	H – 400 H – 750 V – 800	1066.190	41.976	4900	177.8, 203.2, 228.6, 254	7, 8, 9, 10
28 41 55	H – 400 H – 600 V – 800	1226.134	48.273	4300	203.2, 228.6, 254	8, 9, 10
28 41 50	H – 400 H – 600 V – 725	1410.030	55.513	3700	203.2, 228.6, 254, 304.8	8, 9, 10, 12
14 26	H – 200 H – 380	1748.536	63.840 63.840	3200 3200	254, 279.4, 304.8 355.6	10, 11, 12, 14 10, 11, 12, 14
7	H – 100	1864.792	73.417	2800	254, 304.8, 355.6	10, 12, 14



Standardization of Compressor Components

In developing our compressor product line, we focused on standardizing components and hardware to reduce costs and improve reliability across a wide array of applications. Our current product line consists of 15 standard frame sizes, which are scaled from the 38M median frame size. Casing bores and internal aerodynamic hardware, such as impellers, diaphragms, and shafts, are scaled. Scaling aerodynamic components improves performance predictability and increases reliability by preserving geometric similarity across frame sizes. Bearings and seals are selected from vendor standard sizes for each application.

OTHER FEATURES

At Elliott, we maintain an environment of continuous improvement through process innovation. Elliott's engineers continually examine compressor components to find ways to support our goals of higher efficiency, lower cost, simpler maintenance, and reduced cycle time.

Interstage and balance piston sealing is accomplished through two component features. First, we use abrasable or deflection-tolerant materials such as fluorosint or nickel-graphite on stationary sealing surfaces. Second, we machine teeth onto the rotating surfaces. These features increase efficiency by reducing gas recirculation and minimizing the potential for shutdowns resulting from damaged seals.

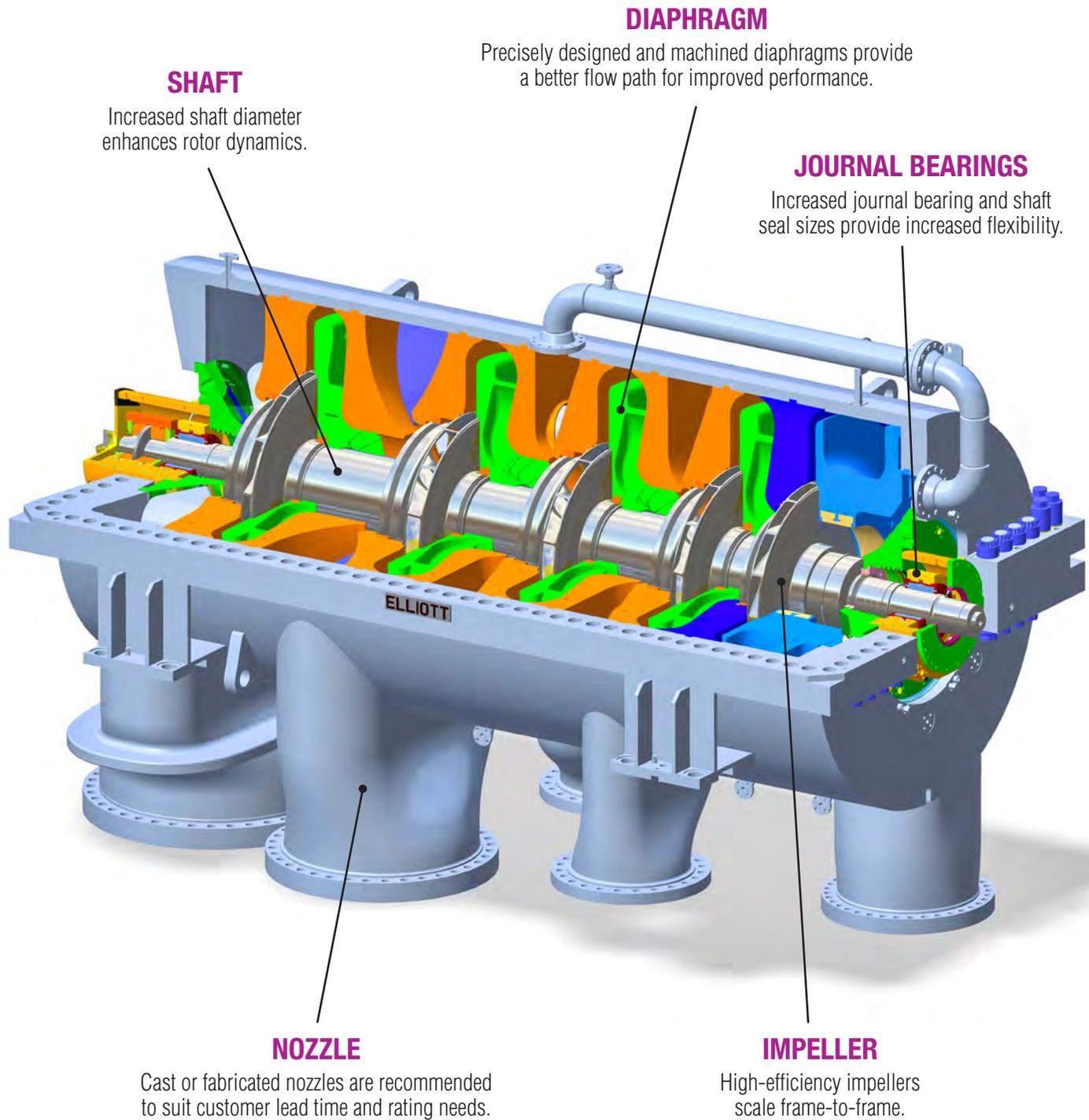
Elliott offers shaft seals to meet our customers' needs in all applications. Dry gas seals are standard and are available as single, tandem, double, or triple designs. The tandem or triple gas seal designs include an intermediate labyrinth, which can be buffered for additional emissions protection. Our customers realize cost savings by eliminating expensive seal oil systems and the need to dispose of contaminated oil. Gas seal buffer system engineering and manufacturing are available at Elliott's Packaging Solutions operation in Belle Vernon, Pennsylvania.

Alternative seal designs include labyrinth or dry carbon ring seals for low-pressure services, mechanical contact seals (Elliott's patented Iso-carbon® design), and bushing seals (Elliott's Iso-sleeve™ design). For mechanical contact and bushing seals, a cartridge design is also available. This enables easier installation and removal of the complete seal assembly. Buffer connections are standard for all seal designs.

Reliability, quality, and safety are hallmarks of all Elliott-designed components. For example, as a design standard, replaceable journal bearings are steel-backed and babbitt-lined with a five-shoe tilting pad. Thrust bearings are double-acting and self-equalizing. Center pivots typically are used to make assembly easier and to provide maximum protection if reverse rotation occurs. Chrome-copper pads are applied for both journal and thrust bearings for high oil temperature applications.



■ PROVEN TURBOMACHINERY TECHNOLOGY



MANUFACTURING AND TESTING CAPABILITIES

Elliott uses high-quality production techniques that minimize cycle time and costs while providing our customers with the most competitive and reliable products. Our engineering and manufacturing facilities in Jeannette, Pennsylvania, and Sodegaura, Japan, rank among the world's most advanced for turbomachinery design, production, and testing.

Elliott's combined manufacturing capabilities include Masterhead machining centers for casing machining, rotor machining centers, and diaphragm machining centers. Our rotor balancing facilities include a state-of-the-art Schenck Trebel-designed balancing machine housed in a bunker-style vacuum chamber. The top of this reinforced concrete facility slides away via hydraulic motors, permitting rotors to be lowered onto the balancing equipment. Housed there are three pairs of bearing pedestals that can support rotors weighing from 130 to 44,000 pounds (59 to 19,958 kg). Elliott's world-class Bearing Design and Manufacturing Center is fully equipped and staffed to manufacture and service all makes, models, and types of bearings. Our test facilities enable us to validate the mechanical integrity and performance of our components and overall systems. Elliott's main test facility contains a high-volume, closed loop, specially designed cooling system that can test gas turbine-driven compressor trains at full loads up to 100,000 HP.



■ GLOBAL SERVICE AND SUPPORT

Elliott offers comprehensive service and support for all types of turbomachinery regardless of the original manufacturer. Our experienced engineers, metallurgists, technicians, welders, and mechanics have the expertise and experience to keep equipment performance high and maintenance costs low.

Elliott has a global network of service centers that are registered to ISO 9001 or have structured quality management systems. They provide installation, maintenance, repair, overhauls, parts, rerates, modifications, and training, 24 hours a day, 7 days a week. Supported by our global network of repair centers, our field service teams are recognized for their hands-on experience with comprehensive overhauls; project management; resource planning; subcontractor control; installation and commissioning, and on-site repair. Elliott Technical Services provides practical, timely and cost-effective solutions for complex turbomachinery problems. Rerates and modifications by Elliott Engineered Solutions enhance operating efficiency and extend the life of rotating equipment from any manufacturer.



Elliott is fully compliant with all relevant industry standards including American Petroleum Institute (API), ANSI, Asian Productivity Organization (APO), Canadian Registration Number (CRN), Canadian Standards Association (CSA), and Conformité Européenne / Pressure Equipment Directive (CE/PED). We are accredited by the American Society of Mechanical Engineers (ASME), holding both the U and the R Boiler and Pressure Vessel (BPV) certifications. We adhere to the principles of the American Society of Nondestructive Testing (ASNT) and are SNT-TC 1A compliant.





Elliott Group is a global leader in the design, manufacture, and service of technically advanced centrifugal compressors, steam turbines, power recovery expanders, cryogenic pumps and expanders, and axial compressors used in the petrochemical, refining, oil & gas, liquefied gas, and process industries, as well as in power applications.

Elliott Group is a wholly owned subsidiary of Ebara Corporation, a major industrial conglomerate headquartered in Tokyo, Japan.



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T H E W O R L D T U R N S T O E L L I O T T



COMPRESSORS ■ TURBINES ■ CRYODYNAMICS ■ GLOBAL SERVICE