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High Pressure Pneumatic Compressors Users Guide For Aerospace Applications

RATIONALE

This document has been determined to contain basic and stable technology which is not dynamic in nature.

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1. SCOPE:

Gas compressors (air and other compressible fluids) have been used sporadically since the 1940's for various utility functions in aerospace applications. They have been used to provide power to gun purge and drive systems, engine or APU starters (recharge accumulators), reservoir pressurization, cockpit pressurization, braking systems, canopy seals, engine control devices, landing gear activation, and boosted flight controls (see Table 1). In current state-of-the-art aircraft, most pneumatic system power is extracted from a stage of compression in the turbo-jet engine. As more and more demands are put on new generation engines for fuel economy and performance there is an increasing need for a new source of pneumatic power. This document is intended to describe current state-of-the-art technology in compressors, define the limitations, discuss enhancements needed and attempt to predict the needs of the future.

1.1 Purpose:

The information contained herein was compiled to describe what technology level currently exists, typical applications, user experience and limitations and recommendations for development of new technology necessary to meet projected demands of the future. Those who should benefit from this document would be:

a. System integrators responsible for utilizing gas compressors in new aircraft systems.
b. Designers not familiar with the capabilities and limitations of airborne compressors.
c. Advance systems development designers needing trade-off information for new systems concepts.
d. Compressor design engineers with responsibility for up-grading existing designs.

1.2 Field of Application:

This SAE Aerospace Information Report (AIR) establishes the characteristics of high pressure piston type pneumatic compressors. The focus is to document data and recommendations for use in aerospace applications.

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TABLE 1 - High Pressure Compressors
Airborne Applications

Aircraft	Function	Capacity (SCFM)	Pressure psi/kPa	Drive	Weight (lb/kg)	Comments
Lockheed Electra	Utility Power	4.4	3400/23 400	Hyd. motor	23.4/10.6	
DC-8		4.0	3000/20 640	Hyd. motor	22.0/10.0	
F-4	Canopy Seal	2.4	3000/20 640	Hyd. motor	14.0/6.4	
F-27	Flight and Utility	2.0	3300/22 700	Eng. G/Box]	10.5/4.8	All pneumatic aircraft
KC-135		2.4	3000/20 640	AC motor	31.4/14.2	Includes moisture separator
707 (USAF)	Utility Functions (Emergency	4.6	3000/20 640	Hyd. motor	34.5/15.6	Includes moisture separator and purification system
F-227	Flight and Utility Power	2.0	3300/22 700	Eng. G/Box]	22.0/10.0	All pneumatic aircraft
C-5A		2.4	3000/20 640	Hyd. motor	28.6/13.0	Includes moisture separator and purification system
C-17	Nitrogen Supply OBIGGS	1.0 (#/min)	3000/20 640	Hyd. motor	115/52	Integrated into package
B-2	APU start	0.34 (#/min)	1000/6880	APU-Bleed	32.4/14.7	Integrated into package
F-117	APU start	0.34 (#/min)	1000/6880	APU-Bleed	20.2/9.2	Integrated into package
F-22	APU/EPU start	0.08 (#/min)	4800/33 024	Hyd. motor	16.2/7.3	Integrated into package
AH-64 (Mod)		TBD	1000/6880	Trans.	TBD	IPAS - Integrated Pressurized Air Sub-System

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1.2.1 Classification: High pressure reciprocating piston compressors are positive displacement devices with two or more stages with output pressures of 1000 psi (6890 kPa) and above. Typical compressors are two to four stages with output pressures up to 3000 psi (20 700 kPa). See Figure 1.

1.2.2 Types: This document will focus on piston-type, positive-displacement compressors rather than rotary-screw or roots-type which are typically used in much higher flow applications.

1.3 Lubrication:

1.3.1 Wet Sump: Lubrication and cooling provided by a wet sump which lubricates the pistons, connecting rods, and bearings.

1.3.2 Oil-free: Includes piston-type activating mechanisms with no lubrication on the pistons or valves. Bellows type seals and wipers are used to isolate the pistons from the sump oil.

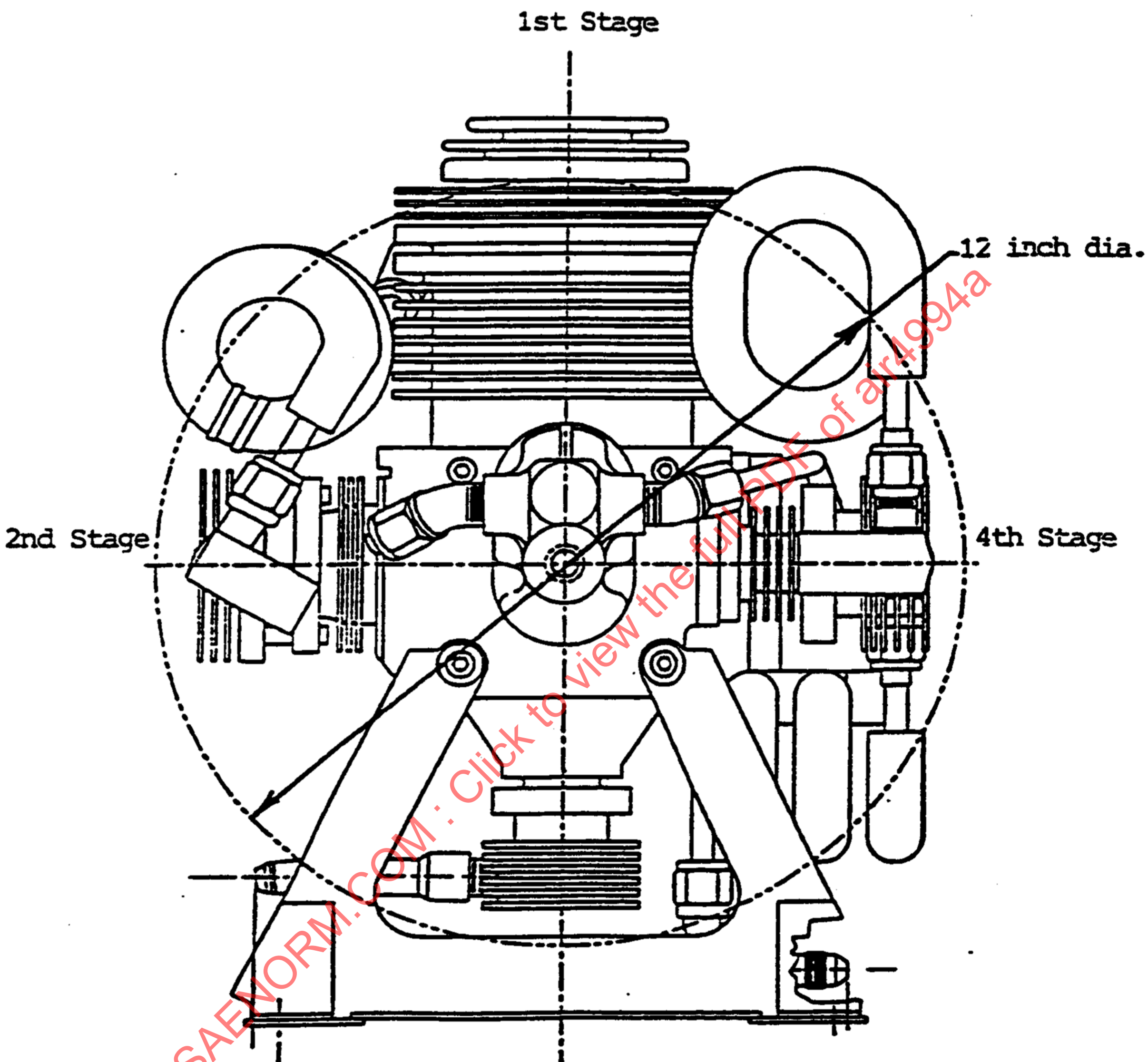

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FIGURE 1 - Typical 3000 psi Aerospace Compressor (4 Stage)

1.3.3 Oilless: A compressor that uses no oil. All bearings are pre-packed and sealed.

1.4 Capacity:

Compressor output performance is typically specified in standard cubic feet per minute or SCFM at an appropriate discharge pressure in pounds per square inch (psi) or kilo pascals (kPa). Small capacity units are usually specified by mass flow (lb/min), (Kg/min), and an appropriate discharge pressure. Typical applications range in capacity up to 17 SCFM and 4800 psi (32 600 kPa).

1.5 Compressor Driver:

Typical drive mechanisms include:

a. Transmission (see MIL-C-6388)
b. Engine (see MIL-C-6388)
c. Hydraulic motor (see MIL-C-6388)
d. Pneumatic (turbine) (see MIL-P-5518)
e. AC/DC electric motor (see MIL-C-6591)

2. APPLICABLE DOCUMENTS:

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1 U.S. Government Publications:

Available from DODSSP, Subscription Services Desk, Building 4D, 700 Robbins Avenue, Philadelphia, PA 19111-5094.

MIL-P-5518	Pneumatic Systems, Aircraft; Design, Installation, and Data Requirements for
MIL-C-6388	Compressor, Air, Aircraft, Shaft Power Driven, General Specification for
MIL-C-6591	Compressor Unit, Aircraft, Electric Motor Driven, General Specification for
MIL-P-8564	Pneumatic System Components, Aeronautical, General Specification for
MIL-STD-810	Environmental Test Methods

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3. SYSTEM INTEGRATION CONSIDERATIONS:

When incorporating a compressor into an airborne application, there are numerous installation and environmental compatibility issues that need to be considered. MIL-P-8564 should be utilized as a guide for interfacing with other pneumatic system components.

3.1 Installation:

a. Mounting: Typical 2 to 4 stage compressors induce torsional vibrations and need to be mounted on shock/vibration mounts if possible.

b. Noise: Piston ripple is a source of excessive noise and can exceed 75 dB. The system designer needs to consider the location and effect on crew members and maintenance personnel in the proximity of the compressor.

c. Compressor Drive: Splined shafts are considered to be the best design for extended life. The drive mechanism should have adequate inertia and structural strength to absorb the compressor torque pulsations. Failure to examine both for compatibility could result in premature driver failures. Consideration should be given to the use of nonmetallic spline adapters (muffs) which can preclude fretting corrosion and fatigue and extend the life of the coupling.

d. Moisture Separators (Interstage and Post Compression): Space should be included for the installation and servicing of moisture separators since routine servicing will likely be necessary since cooling and compression results in water coalescing. A precooler upstream of the separator should be utilized to assure efficient performance. Moisture separators of two types may be considered; one way desiccant or a regenerating type. The desiccant of the regenerating type has the advantage of not requiring periodic service. The one way desiccant type is simpler and when used up, the desiccant is removed and replaced.

e. Cooling: Depending on the application, the compressor may be air or liquid cooled. If air cooled, consideration needs to be given to assure ambient air is able to flow across the compressor across inlet and exhaust passages or ducting. The compressor designer should be capable of providing the minimum air flow requirements for each duty cycle application.

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3.2 Environmental:

a. Temperature: As in other mechanical equipment, controlling temperature rise is a major factor in predicting performance and life. Present materials used in piston type compressors will support ambient temperature to 165 ×F (73 °C) at maximum duty cycle conditions and -65 ° F (-54 °C) at minimum temperatures. Exotic materials may be required for higher temperatures.

b. Vibration/Shock: The particular compressor application must reflect expected levels of vibration and shock. The MIL specification or detail specification should define the method, duration, and amplitude of testing. If vibration isolators are utilized, they should be included as part of the actual test.

3.2 (Continued):

c. Sand and Dust: The compressor cooling fan acts as a vacuum generator and will accelerate sand erosion. Care should be taken when conducting the test to assure the sand is ingested in a uniform dispersal pattern.

d. Salt Spray: Typical state-of-the-art compressors use ductile iron for cylinder sleeves. If a particular application requires exposure to sea water environment, the designer may want to consider a CRES material to preclude corrosion of the external and internal parts exposed to the environment. When using corrosion resistant steels, consideration must be given to the reduced heat transfer capabilities over a typical iron cylinder sleeve.

e. Inlet Filtration: If the particular application may experience any of the aforementioned environments the designer should consider the use of an inlet filtration device.

4. DESIGN AND CONSTRUCTION:

A high-pressure compressor, whether for air or another gas, may consist of the following additional components: bleed valve, back-pressure valve, relief valve, check valve, pressure switch, unloader valve, and drive motor as shown in the schematic in Figure 2. In the case of air compression, and some other gases, an inlet filter and a moisture separator/drier system will be required. Also, in some cases, an inlet pressure regulator will be required. On lubricated compressors, an oil separator may be required downstream of the compressor.

Since reciprocating compressors of this type run relatively slowly, a speed reducer may be required. As the drive rotates the compressor, the working fluid medium is successively compressed in several stages. It leaves the last stage and enters the moisture separator (some applications require interstage moisture separation), then a chemical drier (if so equipped). It then encounters the back-pressure valve which regulates the pressure of the working fluid medium before entering the rest of the system.

The relief valve prevents stage over-pressurization; the bleed valve allows relief of pressure in the system for maintenance. The unloader valve dumps the high-pressure trapped between the compressor and the check valve after the compressor stops running, thus purging the trapped gas from the moisture trap and chemical drier. This action causes the moisture separator to dump and also purges the lines if the separator should be located remote from the compressor. Some electric motor driven systems use a back pressure valve to maintain a minimum back pressure on the moisture removal components to insure more effective separation, since the efficiency of these items is proportional to the absolute pressure. Hence, the chemical drier life is extended, especially during the initial stage of the charging process. The pressure switch starts and stops operation as required to keep the system storage vessel at the desired pressure.

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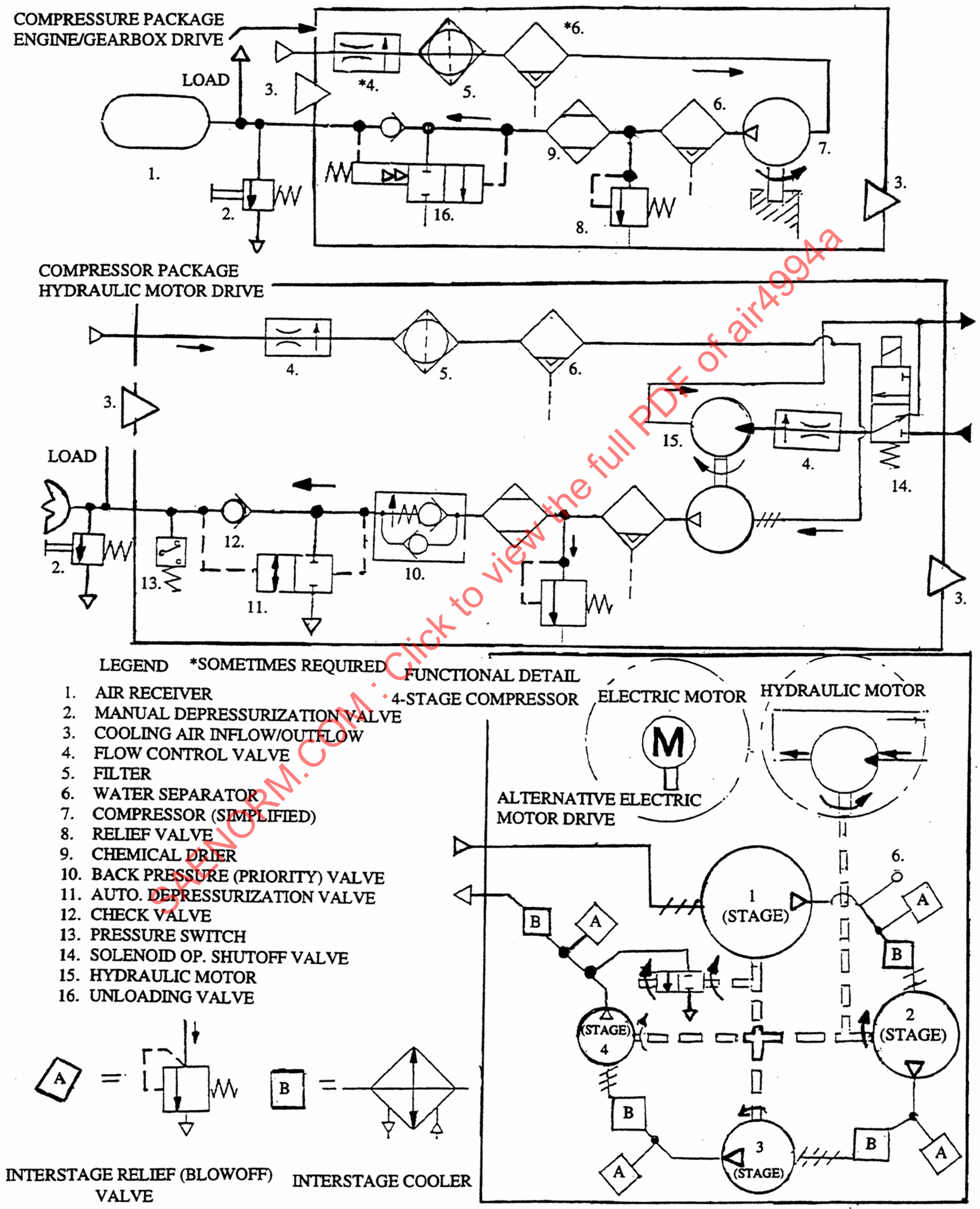

FIGURE 2

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4. (Continued):

In general, lubricated compressors can be used where oil in the discharged working fluid is not a problem in a particular application. As a rule of thumb, such lubricated compressors can be used for air or inert gases where no more than one pressure vessel is in the system. Some danger will still exist from compression ignition of oil in the vessel (from possibly connecting an external high-pressure source and suddenly pressurizing the vessel from low pressure). Such risk must be analyzed for each application. There is also a risk involved when pressurizing hydraulic actuators in emergency operations.

There is also some risk in using an oil-free compressor for compressing oxygen. Even a trace of oil in the discharge gas can pose a danger, because of the possibility of a failure of the wipers or seals. The elimination of all oil liquid lubricants is an important safety feature. Thus, the oilless compressor is an outgrowth of the oil-free type. With the oilless type, even a complete failure of the grease-lubricated bearings does not create a threat, since very little grease is used, and it is not fluid. It is important to use the right type and amount of grease and the right type of bearing and seal for the application.

Rotor burst must be considered as in any other airborne equipment. Sufficient analysis should be done to assure there is no danger from flying parts in the event of a fracture.

An auxiliary benefit of the oilless compressor is that it can be mounted in any orientation, while the types using oil for crankcase lubrication may have a fixed installation attitude.

5. PERFORMANCE AND LIFE:

5.1 Performance/Duty Cycles:

5.1.1 Drive speeds depend on the type of compressor. Typical oil-free or oilless compressors operate at 2000 rpm or less, regardless of size. Typical lubricated units can operate up to 4000 rpm. The speed limiting factor is piston speed, which is material dependent, and which typically should not exceed 360 ft/min (110 m/ min) at 3000 rpm.

5.1.2 Duty Cycle: Compressors are designed for continuous duty assuming that operating temperature can be maintained at an acceptable level.

5.1.3 Efficiencies: Typical efficiencies of a 3000 psi (20 700 kPa) compressor operating at nominal speed would be 75% volumetric, 78% mechanical, for an overall efficiency of 56%. Since overall efficiencies are relatively low, it is important to assure there is adequate cooling capacity to maintain acceptable operating temperatures.

5.1.4 Servicing: The compressor designer should establish the period of operation prior to servicing the moisture separator and checking the oil level (on lubricated units) and/or checking the chemical dryer cartridge (normally containing silica gel). This can vary depending on the duty cycle, however, it is not normally less than 1000 h of operation. A maximum allowable level of oil consumption prior to removal and replacement should be specified by the compressor designer.

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5.2 Life/Reliability:

5.2.1 MTBF: Current state-of-the-art compressors are experiencing MTBF's of 2000 h, depending on the application and duty cycle. Future generation design goals are 20 000 h. Typical failure modes or reason for removal are:

a. Leaking shaft seals (lubricated compressors with wet sump)
b. High oil consumption in lubricated designs
c. Damaged or leaking finned intercooler tubes
d. Low air flow (wear out)

Compressor designers should focus new design concepts on improving or eliminating these problems.

5.2.2 Life: The present military specifications reference a 500 h life. This is considered to be reflective of machines designed in the 1950 to 1960 time frame. New materials and improved sealing devices have pushed endurance testing to levels of 2000 h for typical piston type devices, i.e., hydraulic pump. The system designer can review each application and require endurance and/or reliability growth testing according to the system goals for life.

5.2.3 Servicing and Overhaul: A compressor is considered an LRU (line replaceable unit) and can be overhauled at an appropriate depot or repair station. Servicing is limited to checking the oil level (crankcase type units) and draining moisture (water) from the moisture separator if included with the compressor.

6. COMPRESSOR PERFORMANCE TEST REQUIREMENTS:

The following information is compiled to summarize the minimum requirements that need to be included in a model specification for a new compressor application.

6.1 Installation/Performance Requirements:

a. Drive mechanism
b. Mounting provisions
c. Rated

1. Volume (SCFM)
2. Discharge pressure (psi/kPa)
3. Inlet pressure (psi/kPa)
4. Speed (rpm)
5. Altitude (ft/m)
6. Vibration/shock
7. Wet or oilless design

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