Appendix "A"

1.0 Reliability Centered Maintenance (RCM)

Reliability Centered Maintenance (RCM) is the process that is used to determine the most effective approach to equipment maintenance. RCM involves identifying actions that, when taken, will reduce the probability of equipment failure and which are the most cost effective. RCM includes the entire life cycle of the equipment starting with the equipment design, manufacturing/ construction and installation. RCM seeks the optimal mix of Condition-Based Actions, other Time- or Cycle-Based actions, or a Run-to-Failure approach. The ultimate goal of RCM is to minimize maintenance and operational costs. This appendix is a condensed version of RCM related topics with a focus on predictive maintenance, acceptance testing utilizing predictive and/or proactive technologies, resulting in the creation of baseline data for each equipment asset and hopefully a more reliable piece of equipment.

1.1 RCM Acceptance Testing with Baseline Data

Baseline data is condition monitoring information that is representative of equipment in a new and/or properly operating condition. The baseline data is the foundation of the predictive trending analysis required to forecast equipment condition. It is important that this data is established as early as possible in the life of the equipment. The baseline readings and periodic monitoring data should be taken and recorded under the same conditions (or as close as can be achieved), and will be used for acceptance testing. The Equipment Engineering Flight organization, 76 MXSS/MXDEA, will provide acceptance testing of equipment components using advanced technology listed in section 1.2. Final acceptance of the equipment will include a signature by the RCM Engineering Team Lead verifying equipment reliability; see section 1.5 of Appendix B. When the equipment has been accepted by the Government, the final data obtained will be used to establish the original installed equipment health baseline data for this equipment or system.

1.2 Criteria by Technology

1.2.1 Vibration Monitoring

The development of specific vibration criteria for every machine for all possible operating speeds, in all applications, and in every mounting arrangement, is very difficult. Vibration amplitude varies with operating speed, load, and mounting arrangement, so developing criteria based solely on amplitude can be misleading. The frequency content of the spectrum is often as important as the amplitude. For example, the presence of a frequency associated with an inner race defect on a new bearing is unacceptable, regardless of the amplitude.

Therefore; the vibration specifications utilized for acceptance testing will be based on generic International Standards Organization (ISO) 3945, ISO 10816, American National Standards Institute (ANSI), MIL-STD-167-1, MILSTD740-2 (Appendix C) and Lockheed Martin vibration specification LMMSS SPECIFICATION NO. V 1.0-1997. Equipment failing the vibration tests will be rejected by the Government.

1.2.1.1 Vibration Monitoring Locations

1. **Data Gathering Points**—For all rotating equipment provided under the contract, the contractor shall provide when possible vibration monitoring points using the following guidelines:

a. The contractor has the option of machining the equipment case in order to achieve a flat and smooth spot of 1" diameter with a surface finish of 32 micro-inches RMS, or installing magnetic accelerometer pads either by welding or stud mount. The accelerometer pads must meet the size and finish requirements of the machined spot face.

b. The contractor shall ensure monitoring locations are positioned on structural members. Installation of accelerometer pads on bolted cover plates or other non-rigid members are not acceptable.

c. Data gathering points are to be located in a horizontal, vertical and axial orientation with respect to component bearing/shaft centerline.

2. **Blowers & Fans**— Equipment containing Motors on blowers and/or fans shall have accelerometer pads installed in the radial (2ea) and axial (1 ea) directions as previously described. Fan bearings shall be monitored radially in the vertical direction.

1.2.1.2 Bearing Information

1. **Drawings**—The contractor shall provide to the procuring organization section drawings that show the component arrangement for all rotating equipment supplied under the contract. The section drawings shall accurately depict the bearing support structural arrangement, be drawn to scale, and show the dimensions to the centerline of all rotating shafts.

2. **Bearing Data**—The contractor shall provide to the procuring organization the bearing manufacturer and part number for all bearings used in all rotating equipment supplied under this contract. The information shall be included on the sectional drawings for each bearing location.

3. **Operating Data**—The contractor shall provide the procuring organization with the operating speed for constant speed units and the normal operating speed range for variable speed equipment. Additional information shall be provided for:

a. Nation bearing numbers.
b. All vibration fault frequency information along with component locations.
c. All counts on number of blades, lobes, pistons, gears, impellers, stages.
d. Pulley sizes, belt information.
e. Coupling type and clearances.
f. Acceptable criteria for alignment results after laser alignment.
g. Thermal growth specification for alignment purposes.

4. **Lubrication Data--** The contractor/manufacture shall provide to the procuring organization the following information on all liquid lubricants contained within equipment/system or in bulk (5 gallons or more) supplied under this contractor/manufacture. In-turn the procuring organization will provide 76th MXSS/MXDEA with the following information:

a. **Liquid Lubricants**
Viscosity grade in ISO units
Viscosity Index
AGMA and/or SAE classification as applicable
Mil Spec and/or NATO Code as applicable
Cincinnati Milacron Specification Number as applicable
Viscosity in Centistokes (cst) @ 40° C and 100° C
Type Additive package. Example: ZDDP, Rust inhibitors, Foam inhibitors.
Neutralization, the TBN (alkalinity) and/or TAN (acidity).
Flash point
Pour point

b. **Grease Lubricants**
National Lubrication and Grease Institute (NLGI) Number
Type and percent of thickener
Dropping point
Maximum Service Temperature
Base oil viscosity range in SUS or centipoise
The following formula shall be used to calculate SUS and absolute viscosity:

$$\mathbf{Z = p_t(0.22s - 180/s)}$$

where: Z = absolute viscosity in centipoise at test temperature
s = Saybolt Universal Seconds
p_t = specific gravity at test temperature
t = temperature (deg F)

Changes in density can be calculated by the formula:

$$\mathbf{p_t = p_r - 0.00035(t-60)}$$

where: p_r = specific gravity at the reference temperature (normally 60 deg F)
t = temperature (deg F)

1.2.1.3 Fans, Blowers

The contractor shall provide to the procuring organization the following information on all fans/blowers supplied under the contract:

- Type of fan or blower
- Number of rotating fan blades/vanes
- Number of stationary fan blades/vanes

- Rotating speed(s)

The contractor shall provide to the procuring organization the following additional information if the fans/air handlers are belt driven:

- Number of belts
- Belt lengths
- Belt Part Number
- Diameter of the drive sheave at the drive pitch line
- Diameter of the driven sheave at the drive pitch line

For all fans supplied under the contract, the contractor shall ensure sufficient access to the fan is present in order to allow for cleaning and in-place balancing of the fan.

1.2.1.4. Rotating Machinery Alignment

1. All directly shaft-driven flexibly coupled rotating machine alignment shall be performed using only laser shaft alignment systems.

2. Machine bases shall be clean, level, planar, and rigid.

3. 'Soft foot' (machine frame distortion) shall be eliminated prior to final alignment.

4. Target specifications for expected machine movement during operation shall be considered and taken into account (if available) when performing final alignment of the machines. If target specifications are not available, all due diligence shall be exerted to obtain this information via the methods detailed below. These methods shall prevail in the following order of priority of acceptance:

    a. Data derived from a study of positional change.
    b. Machine vendors' or manufacturers' recommendations.
    c. Calculation performed via the TLC method (detailed in Table B.)
    d. A "hot alignment check".

    e. Final shaft alignment shall be performed to the relevant alignment tolerances specified in the "Alignment Tolerances" charts in Table A. Tolerances in the "excellent" column are design goals when new and tolerances in the "acceptable" column are indicative of equipment that has been in use for a specific time period usually one year or less.

    f. All dimensions shall be measured and be accurate to the nearest 1/8th inch (0.125"). A complete alignment report shall be generated from the device and printed out on a connected printer or stored on a PC for archival and documentation purposes.

Table A
Shaft Alignment Tolerances

SHAFT ALIGNMENT TOLERANCES (SPACER COUPLINGS)		
Angularity (Angles α and β) in mils per inch or Projected Offset (Offset A, Offset B) in mils		
RPM	EXCELLENT	ACCEPTABLE
600	1.8	3.0
900	1.2	2.0
1200	0.9	1.5
1800	0.6	1.0
3600	0.3	0.5
7200	0.15	0.25

Spacer coupling tolerances are to be applied anytime the distance between flex planes in a coupling or a across a spacer shaft or spool piece is equal to or greater than 4 inches.

Table B
Thermal Growth Calculation Method

SHAFT ALIGNMENT TOLERANCES (SHORT COUPLINGS)				
	EXCELLENT		ACCEPTABLE	
RPM	Offset (mils)	Angularity (mils/inch)	Offset (mils)	Angularity (mils/inch)
600	5.0	1.0	9.0	1.5
900	3.0	0.7	6.0	1.0
1200	2.5	0.5	4.0	0.8
1800	2.0	0.3	3.0	0.5
3600	1.0	0.2	1.5	0.3
7200	0.5	0.1	1.0	0.2

Short coupling tolerances are to be applied anytime the distance between flex planes in a coupling is less than 4 inches.

Formula:
T x L x C = the thermal growth at any measured point along the shaft centerlines, in mils.
Where:
T = change in temperature in °F (Δt).
L = distance of material involved, in inches.
C = coefficient of linear expansion.
Common coefficients (C) in mils per inch of material per °F change in temperature:

Aluminum	0.0126
Bronze	0.0100
Cast iron, Gray	0.0059
Stainless steel	0.0074
Mild steel, ductile iron	0.0063

Input the calculated thermal growth values at the machine support locations into the laser alignment system utilizing the Thermal Growth function.

The government shall perform a vibration analysis survey during the start-up phase of the installation. All defects noted by the government shall be corrected by the contractor at no additional expense to the procuring organization. The government will re-survey repaired areas to assure proper corrective action has been taken.

1.2.2 Thermography

Electrical—The government will perform a thermographic survey on all electrical distribution equipment, motor control centers, and transformers during the start-up phase of the installation.

Motors and Bearings— Large machines shall be scanned closely. Abnormal hot spots on the body may indicate flaws in the stator windings. The surface temperature of a motor is normally lower than the winding temperature. Bearing temperatures are normally higher than the housing temperature.

Any defects noted by an observable difference in temperature of surveyed components or unexplained temperature rise above ambient shall be corrected by the contractor at no additional expense to the procuring organization. The government will re-survey repaired areas to assure proper corrective action has been taken.

There are two basic criteria for evaluating temperature conditions; differential temperature (ΔT) and absolute temperature. Each is described below.

a. **Differential Temperature (ΔT)** - Temperature difference criteria are simple, easy to apply in the field, and provide an adequate qualitative screening system to identify thermal exceptions and problems. The ΔT criteria compares component temperature to the ambient temperature and may be used for electrical equipment. ΔT may also be used for mechanical components.

b. **Absolute Temperature**—Absolute temperature criteria are generally specific to an equipment model, type of equipment, class of insulation, service use, or any of many other salient characteristics. As a result, absolute temperatures are more suited to quantitative infrared thermography and critical temperature applications. The mechanical temperature specifications come primarily from manufacturer's manuals. Electrical temperature specifications are set by three principal electrical standards organizations:

- National Electrical Manufacturers Association, (NEMA) (Appendix C).
- International Electrical and Electronic Engineers, (IEEE) (Appendix C).
- American National Standards Institute, (ANSI) (Appendix C).

1.2.3 Airborne Ultrasonics

The government shall perform an airborne ultrasonic survey during the start-up phase of the installation. The government shall survey electrical equipment for indications of arcing or electrical discharge, including corona. Piping systems shall be surveyed for indications of leakage. Baseline all electric motors for db levels using contact probe. All defects or exceptions noted by the use of airborne ultrasonics shall be corrected by the contractor at no additional expense to the procuring organization. The government will re-survey repaired areas to assure proper corrective action has been taken.

1.2.4 Motor Analysis

The government may perform a motor analysis survey during the start-up phase of the installation in order to verify the information to be provided by the contractor (or contractor's representative) as listed in 1.2.4.1 through 1.2.4.5 below. All defects or exceptions noted by the government shall be corrected by the contractor at no additional expense to the procuring organization. The government will re-survey repaired areas to assure proper corrective action has been taken.

1.2.4.1 Motor Circuit Analysis (Complex Phase Impedance)

Upon motor installation, the contractor shall take and provide to the procuring organization the following acceptance/baseline readings and measurements, first for the motor alone, and then, for motor and circuit together:

- Conductor path resistance
- Inductive imbalance
- Capacitance to ground

1.2.4.2 Motor Current Spectrum Analysis

With the motor installed and operational, the contractor shall conduct an acceptance/baseline spectral analysis on the loaded motor at 75% or greater load, when specified by the procuring organization.

1.2.4.3 Insulation Resistance

Upon installation, the contractor shall take and provide to the procuring organization the following acceptance/baseline readings and measurements; initially, for the circuit or for the motor alone, and then, for the motor and circuit together:

- Dielectric Absorption Ratio (for all motors)
- Leakage current at test voltage

1.2.4.4 Surge Testing

The contractor shall perform surge testing and high potential (high-pot) resistance testing of the motor(s) prior to their installation and procuring organization's acceptance. The contractor shall provide to the procuring organization documentation of test results, including test voltage, waveforms, and high potential leakage current.

1.2.4.5 Start-up Tests

With the motor installed and operational, the contractor shall collect and provide to the procuring organization the following baseline data:

- Coast-down time
- Peak starting current

1.3 Maintainability and Ease of Monitoring

The contractor shall provide for equipment maintainability and ease of monitoring through design. For example, rotating equipment such as fans will shall be equipped with an inspection/ clean out port. Accessibility to these ports shall facilitate inspection and cleaning of the fan blades.

1.4 Design for Reliability

Capital equipment purchased by the Air Force Material Command is depreciated on a ten year cycle; therefore, all equipment delivered shall be designed to last a minimum of ten years with a focus on designing for reliability. Example, all motors utilized on the equipment shall be equipped with aluminum cooling fans (design minimum), no plastic fans allowed.

1.5 Leveling of Equipment Upon Installation

The contractor shall level all installed rotating electrical and mechanical machinery in accordance with original equipment manufacturers (OEM) specifications and this SOW. The government will check the level of the machinery to verify accuracy. Any discrepancies detected by the government will be corrected by the contractor. The government will re-survey the installed equipment to assure proper corrective action has been taken.

1.6 Equipment Health Assessment Checklist

The Equipment Engineering Flight organization, 76 MXSS/MXDEA, will utilize the Equipment Health Assessment Checklist shown on page 9, along with the requirements detailed in sections 1.2 through 1.4 of Appendix B, in order to verify the equipment health and precision installation of the installed equipment as part of the equipment acceptance criteria and to establish the equipment health baseline data of the equipment. Contractor shall fix/ repair any discrepancies found. The Government will then re-run that portion of the checklist until all discrepancies are corrected and the equipment is acceptable to the Government. The RCM Engineering Team Lead will then sign the filled out Equipment Health Assessment Checklist showing no remaining issues to verify the equipment is acceptable. Once the equipment has been accepted by the Government, and the warranty period begins, the Government will continue to utilize the Equipment Health Assessment Checklist, shown on page 9, on a periodic basis to detect equipment anomalies or issues that may require warranty attention. The Equipment Engineering Flight organization, 76 MXSS/MXDEA, will then contact the owning equipment's engineering office of responsibility who, in turn, will then contact the Contract Officer (CO) for warranty support when a problem is detected.

Equipment Health Assessment Checklist

Equipment Description: ______________________________ Date: ______________

Equipment Location: ______________ Equipment Number (If Available): ______________

Auditor Name(s)/Org: ____

Equipment Health Assessment

Infrared/ Motor analysis:

	Yes – Pass	Yes – Fail	No	N/A
Infrared scan electric panels, motors and extreme temperature components?				
Motor analysis/baseline done & acceptable?				
Motor(s) rotation marked and in correct direction?				

Stroboscope:

	Yes – Pass	Yes – Fail	No	N/A
Belts, couplings and/or chains observed & acceptable?				
Other rotating/moving components observed & acceptable?				

Vibration:

	Yes – Pass	Yes – Fail	No	N/A
Overall vibrations levels checked & acceptable?				
Accelerometers or accelerometer pads installed?				

Alignment:

	Yes – Pass	Yes – Fail	No	N/A
Belts, shafts, pulleys and couplings checked?				
Machine Level?				

Ultrasound:

	Yes – Pass	Yes – Fail	No	N/A
Piping scanned for leaks?				
Equipment scanned for abnormal noise?				

Oil/Grease/Fluids:

	Yes – Pass	Yes – Fail	No	N/A
Are all lubricants checked and verified for correct type?				
Are all grease and lube fittings labeled for correct type?				
Are all fluid reservoirs labeled for fluid type and amount?				

Safety:

	Yes	No	N/A
Does equipment have safety guards over belts/chains/rotating equipment?			
Are pinch points marked and/or guarded?			
Does equipment have functioning e-stop device?			
Are stored energy sources isolated in the event of equipment failure?			
Are isolation valves for steam, air, water, etc included and labeled?			
Is the load center panel easily accessible and marked with equipment information?			

Installation:

	Yes	No	N/A
Is equipment installed as per manufacturer's recommendations?			
Check for ease of maintainability (piping unions included, clearance for panel/cabinet doors opening, motor access, shut off valves for utilities, access platforms,...etc)?			
If equipment is designed for a fixed location, is it securely anchored?			

Operational Check:

	Yes	No	N/A
Operational check performed?			
Does equipment function as required?			
Is an operator or engineer present for operational check and POC information provided? Operator: ____________ Engineer: ______________			

Results/Comments: 76 MXSS/MXDEA RCM TEAM LEAD: ______________________________

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ISO 10816-3 Vibration Severity Chart