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AEROSPACE INFORMATION REPORT

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A GUIDE TO AIRCRAFT TURBINE ENGINE VIBRATION MONITORING SYSTEMS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

PARAGRAPH | PAGE NUMBER

1. PURPOSE: The purpose of this Aerospace Information Report (AIR) is to provide information and guidance for the selection, installation, and use of airborne engine vibration monitoring systems and their elements.

   This AIR is not intended as a legal document but only as a technical guide.

2. SCOPE: This AIR is a general overview of typical airborne vibration monitoring (AVM) systems with an emphasis on system hardware design considerations. It describes AVM Systems currently in use.

3. INTRODUCTION: A complete engine vibration monitoring (EVM) system includes all the equipment, data, and procedures used for monitoring and analyzing aircraft turbine engine vibration. Such a complete EVM System is shown in Figure 1. Engine vibration monitoring may be one part of an engine monitoring system that monitors a number of engine parameters or it may be a stand alone system. A distinction is usually made between that part of the system dedicated to monitoring functions on board an aircraft and that part used for ground based monitoring (most commonly with the engine removed from the aircraft and mounted in a test cell). The on board portion is commonly called an airborne vibration monitoring (AVM) system, and it is this part of the complete system that is described in this AIR.

   The primary moving parts of all turbine engines are the rotors and their shafts which, when the engine is producing power, spin at relatively high speed within the engine case. The elements of these rotors, particularly the fan, compressor, and turbine blades are subject to wear and damage, some types of which may unbalance the affected rotor. Increased rotor unbalance causes increased cyclic stress on the structure and on the associated rotor bearings. In addition, the cyclic forces due to unbalance may induce destructive vibration in other engine parts and accessories. Small amounts of rotor unbalance are always present; large amounts usually cannot be safely tolerated by the engine. Most of the AVM Systems now in use were developed to monitor the level of vibration developed to monitor the level of vibration resulting from such unbalance. AVM Systems have also been developed for monitoring the vibration of other power plant elements including afterburners, reduction gears, bearings, transmissions, and accessories. The recent availability of high speed digital signal processing integrated circuits has made it practical to provide very sophisticated on-board vibration analysis in today's systems.

   Among the specific engine problems likely to be detectable by an AVM System are:

   Blade out (fan compressor, or turbine) or portion of a blade missing.

   Blade or blade retainer shift or wear sufficient to cause rotor unbalance.

   Hardware missing from rotors (i.e., bolts, nuts, etc.).

   Blade coating delamination.

   Bearing misalignment or bearing wear sufficient to cause rotor unbalance.

   Oil or debris in rotor or shafts.

   Augmenter (afterburner or reheat) "screech".

4. HISTORY: AVM Systems have been available since the late 1940's, yet there is still disagreement within the aviation industry over the need for this type of equipment. The dissenting views arise primarily from concerns over the validity of the data and center on three issues. First, until approximately the mid 1970's, few AVM Systems accomplished very much vibration data reduction. A typical turbine engine vibration spectrum is shown in Figure 2 (the graphical relationship between time domain and frequency domain - the frequency spectrum - is shown in Figure 3). Separating and amplifying the few frequency components associated with rotor unbalance requires a degree of system sophistication that was not, until recently, either affordable or even practical. Second, the elements of AVM Systems have often not been robust enough for long term use in a jet engine environment. Provisions for good vibration sensitivity and frequency response have often been in conflict with the operational requirement for rugged components. Third, AVM Systems generally have been quite susceptible to electrical interference, chiefly because the piezoelectric accelerometers normally used as the engine mounted transducer are high impedance devices. When proper design and installation care is taken, AVM Systems can produce substantial operating cost savings through the early detection of engine damage or abnormal wear.

5. TYPICAL AVM SYSTEM: All present AVM Systems detect and monitor engine vibration by means of one or more transducers installed on some part of the engine. The signals from these transducers are received by electronic processing devices of various levels of sophistication and then the processed signal is displayed in some form to the flight crew and/or transmitted to other on board monitoring equipment. In some instances it is also recorded for later analysis.

In many jet aircraft, notably those in service with commercial airlines, mechanical vibration is so well isolated from the passengers and crew that engine vibrations would have to be present at very high levels before they could be physically sensed through the airframe. Such vibrations may lead to severe secondary engine damage if not detected by the AVM System. Even if physical vibration is sensed through the airframe, the crew must be able to identify its source; absence of a corresponding AVM System indication may lead the crew to look elsewhere for the cause.

As important as it may be to detect the amount of engine vibration, it is equally important to associate the source of the vibration with a particular engine. In a situation where a rotor has experienced substantial and abrupt damage such as an in-flight bird strike which has caused the complete loss of a fan blade, it may be difficult to quickly determine which engine was affected without reference to an AVM System.

The severity of engine mechanical damage or degradation and its rate of change is of great interest to both the flight crew and to maintenance personnel. Data obtained from an AVM System can provide critical and unique information to support decisions ranging in scope from safety of flight to overhaul and service needs.

6. SYSTEM DESIGN: The first task of an AVM System designer or specifier is to clearly define the purpose of the system and its relationship to the complete aircraft. This definition should include considerations of:

Expected benefits.
System costs.
Type of data to be acquired and how it will be used.
Expected system life.
Maintainability.
Provisions for future expansion.

Great care should be devoted to defining a system which is no more complex than can be justified by its expected benefits, with due regard to system growth over the life of the program. Only after the system is defined as to scope and purpose should individual hardware and software elements be selected or specified.

A logical place to start the consideration of such a system is at the signal source, since the precision and fidelity of a monitoring system is ultimately limited by the quality of the signals at their source.

6.1 Signal Source: Signal quality will depend upon three elements: proper transducer location, appropriate transducer mounting provisions and correct transducer selection.

6.1.1 Location: The transducer mounting location on the engine or accessory must be one which is mechanically well coupled to the component being monitored. This coupling must be established during engine development. The engine manufacturer normally carries out extensive vibration tests during the course of engine development, and the data resulting from these tests provides the basis for initial selection of transducer locations. Final verification of transducer locations should be made through flight tests or engine ground runs on the aircraft.

6.1.2 Mounting Surface/Provisions: Transducer mounting provisions may consist of built-in mounting surfaces, special mounting brackets, or simply attachment points for brackets to be added later. In any case, such provisions should always be included in the original engine design and verified during engine development, even if there are no immediate plans for an AVM System.

6.1.2.1 Interfaces: Mounting Surface/bracket/transducer interfaces should all be flat, clean, metal-to-metal surfaces. Hardened or stainless steel such as 321SS is usually the preferred bracket material. Flatness should be within .0005 in./in. Attachment screw torque should be specified (typically 80% of yield).

6.1.2.2 Mounting Point: The best mounting surface is usually one which is part of the engine itself. If this is not possible or practical, a very rigid bracket is the next best choice. For flange mounted transducers, a "T" section or a very substantial "L" section bracket is usually best. Care should be exercised to avoid introducing dynamic response problems due to bracket resonances within or near the operational frequency range. The installed transducer and mounting bracket should have a first resonance at least three times the highest frequency of interest. For this reason, cantilevered mounting brackets are usually unsatisfactory.

6.1.3 Transducer: Mechanical vibration amplitude is commonly expressed in units of displacement, velocity or acceleration (the relationship is shown in Figure 4) and transducers are available which will sense any of these parameters directly.

6.1.3.1 Displacement Transducers: Displacement sensors are usually used to measure the relative movement of a rotor shaft with respect to the bearing housing on low speed engines with oil film sleeve type bearings. Aircraft turbine engines with ball or roller bearings do not lend themselves readily to this type of measurement.

6.1.3.2 Velocity Transducers: Vibration velocity is quite easily sensed on an aircraft turbine engine by means of a moving coil velocity transducer. This device generates a voltage proportional to the relative motion of a coil and a magnet as one element moves with respect to the other in response to unit vibration. The moving element is spring loaded at both ends and the spring rates are selected so that the transducer's operational range will be above its resonant frequency, see Figure 5. Besides producing an output directly proportional to vibration velocity, the major advantage of this type of transducer is that it produces a large, low impedance signal, on the order of one hundred millivolts per inch per second, which can be easily transmitted over great distances using conventional aircraft wiring. The velocity transducer is rarely used in modern AVM Systems because wear resulting from friction of the moving parts severely limits its life. Also, its frequency response is greatly affected by cross axis excitation and mounting orientation.

6.1.3.3 Accelerometers: Accelerometers are the most widely used type of vibration transducer used in AVM Systems today. They are usually of the piezoelectric type which produces an electrical charge proportional to the acceleration parallel to the sensitive axis of the transducer. The signal from this type of accelerometer is generated by piezoelectric material, either a polarized ceramic such as Lead Zirconate Titanate or a naturally occurring crystal such as Quartz or Tourmaline which is tightly compressed between a mounting surface (or surfaces) and a seismic mass (or masses). Acceleration of the element causes the mass to apply compression or shear forces on the material in accordance with the familiar relationship of force equals mass times acceleration ($F = Ma$). The force causes electrical charges to appear on the piezoelectric material surfaces which are then conducted outside the accelerometer. See Figure 6. Typical accelerometer sensitivities range from 10 to 125 picocoulombs per g (pC/g) of acceleration.

6.1.3.3 (Continued):

Accelerometers are used to measure vibration at frequencies well below their resonant frequency. In general, signals at frequencies up to one fifth of the accelerometer resonance frequency will be essentially unaffected by the resonant rise, while those up to one third of the resonance frequency will be amplified less than 10% by the resonant rise. A typical 50 pC/g compression type accelerometer will have a mounted resonance of about 25 kHz and could be used to monitor vibration in the range of 2 or 3 Hz to about 8,000 Hz. Because of the substantial amount of multi-axis vibration usually present on a turbine engine, the accelerometer selected should be quite insensitive to cross axis motion. A maximum of 5% of the normal axis sensitivity is usually considered to be acceptable. Temperature changes of an engine and, thus the mounted accelerometer during various portions of the operational cycle will affect accelerometer sensitivity, so accelerometers should either be selected for minimum such sensitivity or they should be provided with compensation for the variation in other parts of the system. AVM accelerometers should be hermetically sealed, of rugged construction, capable of sustained operation in the expected maximum temperature environment and should have a true differential output, capacitively balanced.

6.1.3.3.1 Surface Mounted Accelerometers with Connectors: Figure 7 shows two typical surface mounted AVM accelerometers with integral electrical connectors. Accelerometers such as this which use a separate cable are quite easy to install, but they are subject to signal degradation due to connector damage or contamination. A large connector will usually be easier to seal and less susceptible to damage, but its mass may adversely affect the frequency response.

6.1.3.3.2 Surface Mounted Accelerometers With Integral Cables: To avoid the potential problem of connector damage or contamination, some accelerometers are designed with integral cables. Where the cable will not be exposed to temperatures above 500°F, a florocarbon insulated cable, often protected by a metal overbraid and/or conduit is usually used. At higher ambient temperatures, a steel jacketed, mineral insulated "hardline" cable is usually used. Figure 8 shows two typical accelerometers of this type.

6.1.3.3.3 Internal Accelerometers: In some instances, the only suitable location for a trnsducer may be inside the engine near a main rotor bearing. Examples of this type of transducer are shown in Figure 9. Since these transducers are built into the engine during manufacture, it is important that their reliability be very high since replacement in service may be difficult and expensive.

An alternate method of implanting accelerometers in or near a bearing housing consists of using rigid (or semi-rigid) probe type units which can be fitted or removed from the outside of the engine as shown in Figure 10. Such units overcome the risk of high replacement costs in the event of failure but generally require that their installation be carefully considered at the time of engine design.

6.1.3.3.4 Duplicated Accelerometers: Two accelerometers are sometimes used at a single location on an engine so that the two signals may be compared as a validity test. With this arrangement, it is important to have the accelerometers close enough together (a shared mounting bracket is usually the most successful approach) so that they sense the same mechanical vibration. It is equally important that the accelerometers are not so closely coupled that a defect in one could cause or would be likely to occur at the same time as a defect in the other.

6.2 Signal Transmission: There are a number of special considerations for signal transmission which are unique to AVM systems.

6.2.1 Separate Preamplifiers: If the preamplifier is located near or even within the accelerometer body itself, then the difficulties of high impedance signal transmission can be avoided. At the present time, electronic components for use in such amplifiers are limited in temperature to approximately 350°F so, with few exceptions, internal electronics accelerometers are not used for turbine engine monitoring. This temperature limit also poses a restriction on how close to the engine a separate preamplifier may be located. Because the cost difference between conventional wiring and special low noise wiring is usually small compared to the cost and system complexity of separate electronic elements, most AVM Systems have not employed separate preamplifiers and use low noise cable systems.

6.2.2 Cable, Shielding and Grounding: A number of special design features are necessary to preserve the signal from a piezoelectric accelerometer during transmission to the preamplifier.

6.2.2.1 Circuit Type: The accelerometer, cable, and charge amplifier sub-system should comprise a true differential circuit, see Figure 11. With this design, any interference applied to both signal leads, "common mode" interference, will be rejected because only the difference between signals will be amplified.

6.2.2.2 Isolation: The accelerometer sensing element should be well isolated electrically from its case, typically 20 Megohms at the maximum operational temperature, so that voltage differences between the accelerometer mounting point and other points in the system will not appear as signals.

6.2.2.3 Shielding: The signal leads should be fully shielded over the entire cable length and the shield should be grounded at one point, usually the signal conditioner chassis ground.

6.2.2.4 Low Noise Treatment of Cable: When shielded cables are flexed, the relative movement of the cables' constituent parts may cause static electric charges to be generated internally. In a freely moving cable, the charges will vary with respect to time and thus appear to the amplifier as spurious signals. This potential problem, called triboelectric noise, is dealt with by using special low noise cable, as shown in Figure 12, in which the internal parts are wrapped in graphite impregnated tape (PTFE usually) thereby preventing such charge accumulation. To further protect against triboelectric noise, the cable should be secured to minimize cable motion. In high vibration areas such as an engine nacelle, it is usually recommended that the cable be firmly clamped at intervals of not greater than eight inches along its length.

6.2.3 Connectors: In general, there should be as few connectors between the transducer and the first signal conditioning stage as practical. Where connectors must be used, they should be steel shell circular threaded type with self locking engagement or provisions for safety wire. Bayonet type couplings should be avoided because they can permit movement between pin and socket which will appear as noise.

6.2.3.1 Shared Connectors: The connectors associated with the AVM System and located between the transducer and the first stage of signal conditioning should, where possible, not be shared with wiring from other aircraft systems. Where shared connectors cannot be avoided, the companion systems selected should be those with essentially dc signals such as thermocouples, or they should be systems which are used infrequently during flight.

6.2.3.2 Connector Shielding: In a shared connector, any spare contacts should be arranged to surround the two signal contacts to provide some degree of shielding. Alternatively, shielded pin type connectors may be used. The cable shield should, with one exception, always be carried through the connector on one of the connector pins. The exception is when the shield is grounded at each end, it must then be open somewhere in between to avoid "ground loops."

6.2.3.3 Connector Strain Relief: Connectors should be suitably strain relieved to prevent cable fatigue damage and/or generation of triboelectric noise.

6.2.3.4 Connector Sealing: Connectors should be sealed to prevent intrusion of moisture and contaminants such s oil and hydraulic fluid by means of backshell and interfacial seals.

6.2.3.5 Connector Contacts: Special high mating force connector contacts should be used in critical areas on or near the engine to provide positive contact engagement and hence good signal continuity. In addition, contacts which are gold plated will reduce susceptibility to corrosion and fretting, thus insuring maintenance of a low impedance connection. Pin size should be Number 10 or larger.

6.3 Signal Processing: The signal conditioner element of the system may be in the form of an individual avionics enclosure or it may be one circuit element of a more comprehensive system which includes a number of diverse monitoring functions.

6.3.1 Conditioning: With a differential piezoelectric accelerometer as the signal source, the first stage of the signal conditioner is the differential charge amplifer. This converts the high impedance charge signal to a low impedance voltage signal. It is a recommended design practice to make a buffered, wide frequency bandwidth output of the charge amplifier available for external maintenance/analysis where off-line signal processing may be desired. It is also good design practice, in order not to sacrifice the common mode noise rejection characteristics of the amplifier, to avoid any switching before the charge amplifier, either between various accelerometers or alternately between test and accelerometer signals. Where high energy, high frequency signals, such as those due to blade passage, are present, it may be necessary to provide input low pass filtering to avoid saturation of the charge amplifier.

6.3.2 Integration: One integration of the accelerometer signal with respect to time yields a signal proportional to vibration velocity and a second such integration yields a signal proportional to displacement. In general, the parameter most commonly associated with vibration measurements at low frequencies is displacement, at mid frequencies is velocity, and at high frequencies is acceleration. Typical turbine engine rotor speeds are in the frequency range usually associated with the parameter of velocity. Since an integration is functionally a 6 dB per octave low pass filter, each stage of integration will emphasize low frequencies and attenuate high frequencies. This is an important consideration when considerable noise is present in the signal as is shown in Figure 13.

6.3.3 Filtering: If a rotor system operates at a constant speed, as is the case with some turboprop and/or turboshaft engines, then a fixed bandpass filter can be centered at the rotational frequency and the output will be representative of the rotor's unbalance. If, as is usually the case, an engine operates over a range of speeds, then either the filter bands must be wide enough to accommodate the entire rotor speed ranges or narrow bandpass filters must be caused to track the signals corresponding to each rotor as a function of speed.

Careful selection of the filter characteristics is very important to total system performance. The raw signal from the transducer may contain many elements in its spectrum other than the frequencies of interest and some of these elements may be very high in amplitude. If not filtered out, they may be confused with the desired signals and/or result in saturation of the input section of the signal conditioner. Most filtering is done after the charge amplifier, but in some cases, it is necessary to incorporate filters before the charge amplifier (input filters) to avoid saturation (overload). Saturation is most commonly caused by high frequency, high amplitude signals such as those resulting from blade passage, gear mesh, and higher rotor orders.

6.3.4 Output Formats: The output of the signal conditioner must match system requirements for display, recording, or further processing of the signals. This may involve gain or impedance matching for ac or dc analog outputs and special transmitters for digital outputs in accordance with standards such as ARINC 429 or RS-232.

6.3.5 Warning Functions: Warning functions are sometimes provided to alert the flight crew of an event or a change in AVM status. These functions may require lamp drivers, latches, and/or special memory.

6.3.6 BITE/Self Test: Built-in test equipment (BITE) and Self Test should be considered in any new system design. BITE should be a means of detecting and recording faults at the time of their occurrence. Self Test is usually a means of actively checking the operational condition of an item of equipment.

7. TRACKING FILTER BASED SYSTEMS: In a tracking filter system, one or more bandpass filters are caused to be constantly centered at the engine rotor frequencies (or multiples thereof) by reference to the engine tachometer signals. The earliest of these systems employed all analog filtering while the latest designs employ primarily digital signal processing.

7.1 Tracking Filters: Since the function of a tracking filter is to monitor discrete frequencies while maximizing noise rejection, its bandwidth should be as narrow as possible consistent with the required engine rotor tracking rate. In general, the tracking rate (or settling time) of any bandpass filter is inversely proportional to its Q which is the ratio of the bandwidth (usually measured at the -3 dB points) to the center frequency. Noise rejection is a function not only of the bandwidth but of the filter shape or rolloff. The ideal narrowband tracking filter response would, therefore, look something like Figure 14. This filter response can be closely approached with a digital FIR (Finite Impulse Response) filter (for which there is no analog equivalent). Typical FIR and analog bandpass filter responses are shown in Figure 15. A convenient way of describing such filters is to use a shape factor, usually taken as the ratio of the bandwidth at -40 dB to that at -3 dB. A current digital tracking filter based AVM signal conditioner is shown in Figure 16.

7.2 Tachometer Reference: Because a tracking filter based system relies on engine tachometer signals for filter center frequency reference, close coordination is required between the equipment supplier and the engine manufacturer to accurately characterize the ratios and the output over the entire engine operational speed range. Similar coordination is required with the airframe manufacturer to insure that the tachometer signals are adequately buffered at the signal conditioner so the tracking filter does not interfere with other aircraft systems.

7.3 Phase Reference: If phase reference signals are superimposed on the engine tachometer signals, then it is possible to use a tracking filter based AVM System for engine fan trim balance with no other support equipment required. Because of the convenience of on-wing trim balance without additional ground running, engine manufacturers are encouraged to incorporate phase reference signals at the time of the engine design.

8. RESPONSIBILITIES: A vibration monitoring system, like any other condition monitoring system, requires, if it is to be successful, a considerable amount of coordination and cooperation. The parties responsible for developing this type of system usually include the end user, the airframe manufacturer, the engine manufacturer, and the equipment supplier.

8.1 System Requirements: The end user, with the concurrence of the engine manufacturer, should have overall responsibility for clearly establishing system requirements. He should outline, with the assistance of the engine manufacturer, the equipment supplier, and the airframe manufacturer, what is to be monitored, how the data is to be presented, how the data is to be used and what benefits are to be expected from the resulting system. Performance, cost, and maintainability objectives should also be stated.

8.2 Performance Requirements: The engine (and/or engine accessory) manufacturer should have overall responsibility for defining engine performance characteristics, limits, parameter to be monitored, diagnostic strategy, and the environment for the engine mounted components. Assisted by the equipment manufacturer, he should select the transducer(s), determine its (their) location(s) on the engine, and define the filter characteristics. This includes suitable built-in rotor phase reference signal sources.

8.3 Performance Capabilities: The equipment supplier(s) should have responsibility for clearly conveying equipment capabilities to the end user, the airframe manufacturer, and the engine manufacturer. This responsibility includes not only conveying technical choices (current and projected) but also those concerning original cost, life cycle cost, maintainability, and product support.

8.4 System Design Approval and Integration: A single point of responsibility for system performance and effectiveness should be clearly defined at the outset of a program.

8.5 Summary: Experience has shown that careful adherence to a relatively short "do and don't list" will avoid most common AVM System problems. Such a list follows:

8.5.1 Use twisted pair, shielded cable with low noise treatment where temperature does not require high temperature "hardline".

8.5.2 Clamp cables at no more than 8 inch intervals and prevent any cable flexing at the connectors.

8.5.3 Provide sufficient clearance between cables and other parts to prevent contact and abrasion during vibration.

8.5.4 Use threaded steel shell connectors such as MS83723 series with sealed backshells and, in areas of high vibration and temperature extremes, use high mating force gold plated contacts.

8.5.5 Do not include AVM System cables in bundles with heavy current or high voltage ac carrying conductors. Provide a separate cable for each accelerometer. These may be bundled with other low level instrumentation leads, subject to the recommendations contained in Paragraph 6.2.

8.5.6 Use separate interface connectors for each accelerometer circuit. Do not include circuits of any type with the AVM System circuits in the connector.

8.5.7 Avoid cantilever bracket mounting of the accelerometer.

8.5.8 Avoid use of connectors in areas where temperature exceeds the rating of the accelerometer connector or its mating connector. Use integral cable instead.

8.5.9 Use integral cable rather than a very large connector on the accelerometer which could adversely affect frequency response due to accelerometer/bracket resonances.

8.5.10 Make suitable provisions for vibration monitoring transducers, including tachometer and phase reference signals, at the time of engine design.

8.5.11 Use as few connectors between the transducer and the first stage of signal conditioning as possible.

9. TERMINOLOGY AND DEFINITIONS:

9.1 Acceleration, Vibration: The response of a mass to an applied force, usually stated as a ratio, g, of the acceleration with respect to G, the acceleration due to gravity. The first integral of acceleration with respect to time is velocity. Vibration amplitude may be expressed in units of acceleration, velocity, or displacement.

9.2 Accelerometer: A device for measuring acceleration. Most accelerometers used for engine vibration monitoring employ piezoelectric sensing elements which generate an electrical charge signal proportional in amplitude, frequency and phase to the applied acceleration. Devices with internal signal conditioning are also available. These provide voltage or current outputs proportional to acceleration or velocity.

9.3 Airborne Vibration Monitoring (AVM) System: The on-board aircraft engine vibration monitoring system.

9.4 Aircraft Integrated Data Systems (AIDS): The general term to identify a family of systems that acquires, processes, and records data used to determine the functional status and condition of various commercial aircraft systems, including engine and engine components.

9.5 Data Bus: A means of transferring information in digital format. Various data bus standards such as ARINC 429 and RS-232 are widely used in monitoring systems.

9.6 Displacement, Vibration: Vibration amplitude may be expressed in units of displacement: inches, millimeters, or mils (0.001 inches). Displacement is the second integral of acceleration with respect to time. Both peak and peak-to-peak amplitude units are in use.

9.7 Frequency Response: The amplitude response of a spring-mass system as a function of frequency.

9.8 Rotor Orders: The rotational speed of the lowest speed engine rotor is conventionally identified as N_1, the next highest as N_2, and the next highest, if present, as N_3.

9.9 Once-Per-Rev: A colloquial expression meaning either a signal which is provided once per engine rotor revolution or the rotational speed of a particular engine rotor.

9.10 Peak and Peak-to-Peak: Vibration amplitude measurement which has a precise meaning only for simple harmonic motion, i.e. single frequency, vibration. Peak is the maximum amplitude of a sinusoidal function with respect to a zero reference; peak-to-peak is the total amplitude measured from maximum to minimum.

9.11 Phase Reference Signal: A signal - usually electrical - provided on some engines which indicates when a particular point on the low speed rotor passes a reference point on the engine case. The reference signal, which is often super-imposed on the tachometer signal, is useful for dynamically balancing the rotor.

9.12 RMS: Root mean square. An average of a set of values which is obtained by taking the square root of the arithmetic mean of the squares of the individual values. Vibration amplitude expressed as RMS is proportional to the total vibration energy in the frequency band of interest but independent of the frequency distribution within that band.

9.13 Screech: High frequency acoustic noise generated by engine exhaust gas turbulence.

9.14 Spectrum: An array of the frequency component amplitudes of a signal arranged in order of frequency.

9.15 Velocity, Vibration: Vibration amplitude may be expressed in units of velocity: inches per second or millimeters per second. Velocity is the first integral of acceleration with respect to time.

9.16 Resonance, Mechanical: The natural frequency of a spring-mass system. It is proportional to the square root of the ratio of the spring constant to the mass for each degree of freedom.

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TYPICAL COMPLETE AIRCRAFT ENGINE VIBRATION MONITORING SYSTEM

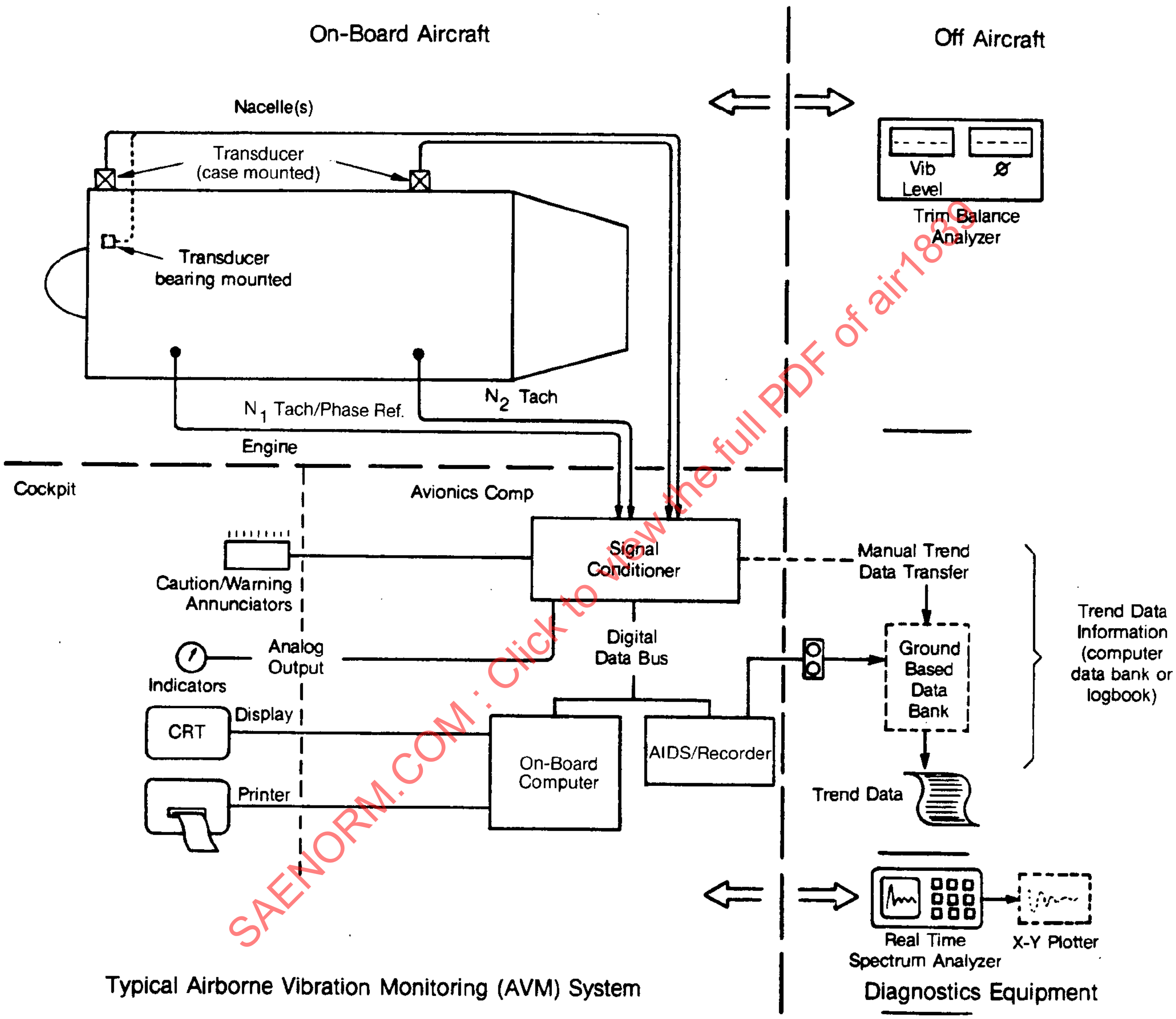

Figure 1: Schematic Of A Complete Engine Vibration Monitoring System

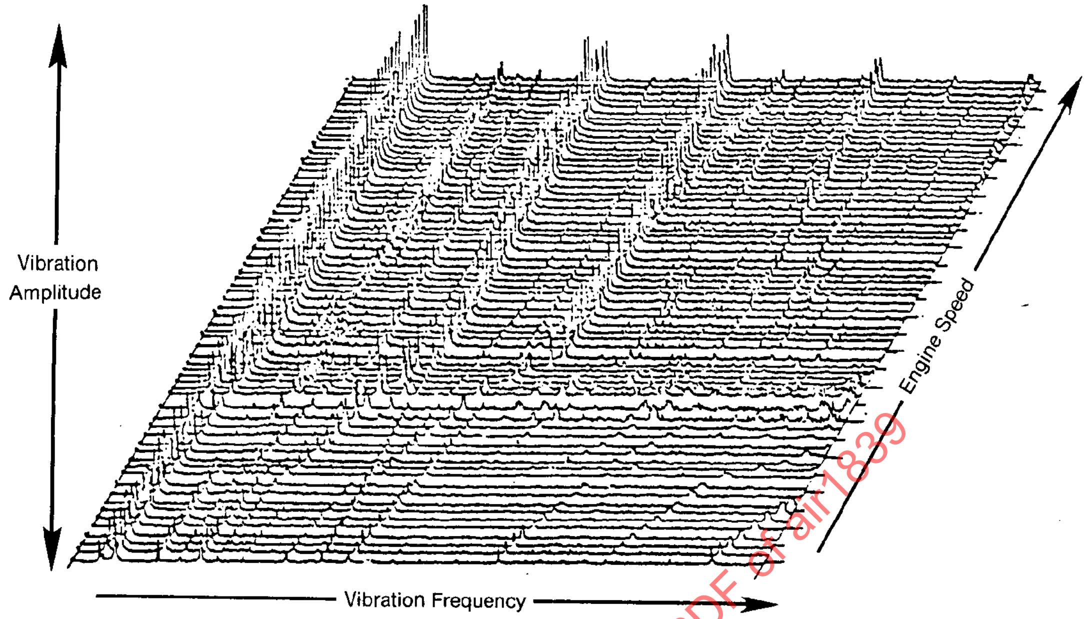

Figure 2: Typical Engine Vibration Spectrum vs. Engine Speed

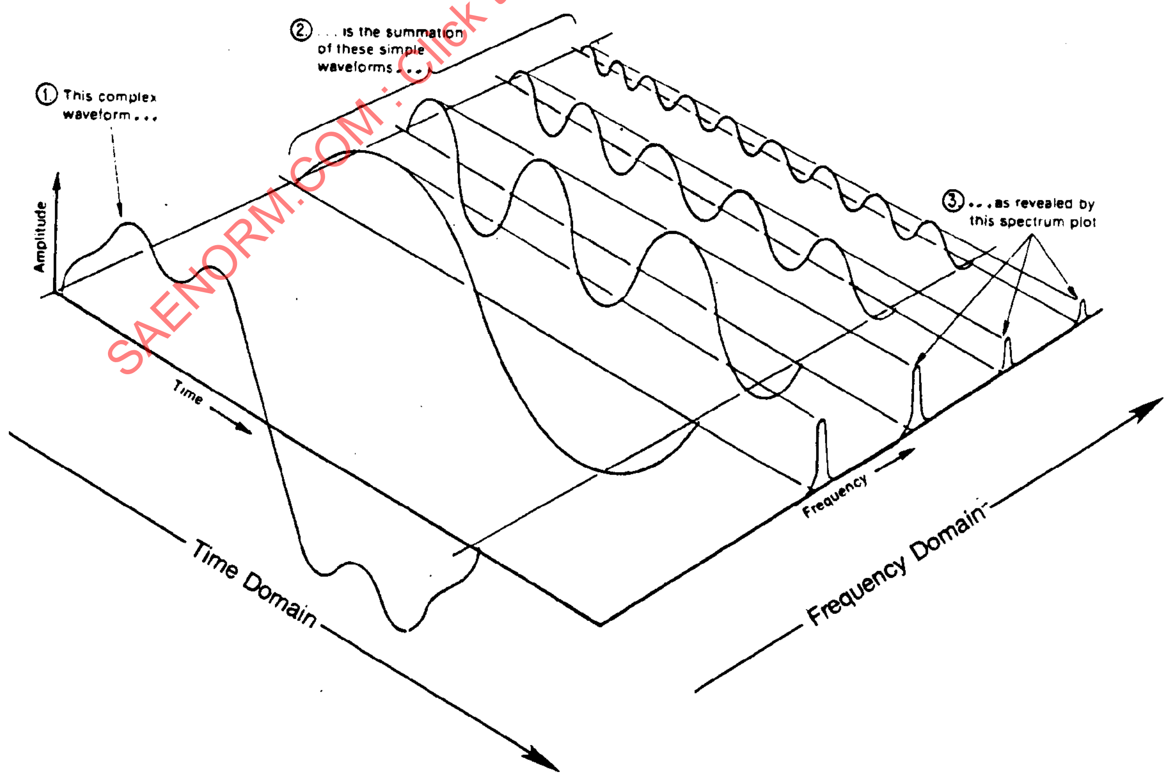

Figure 3: Relationship of Time Versus Frequency Domain

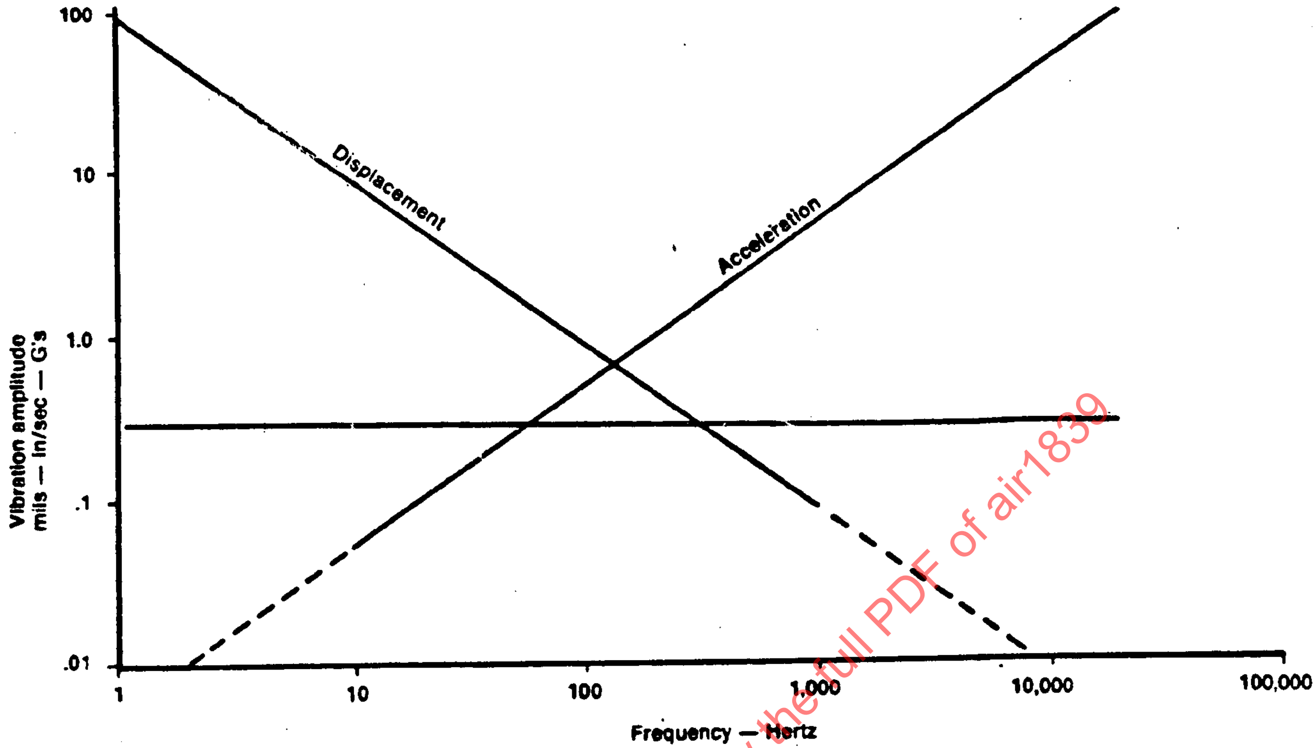

Figure 4: Relationship Between Displacement, Velocity and Acceleration at Constant Velocity

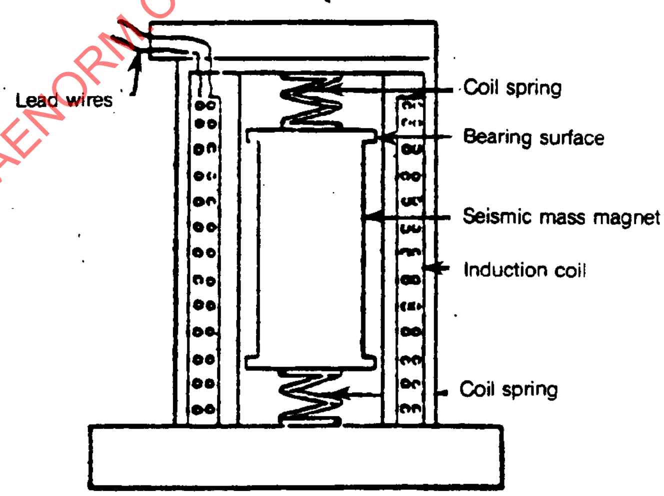

Figure 5: Cross Section Of A Typical Velocity Transducer