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The Design of a Quality System to Support NASA Glenn Research Center Acoustical Testing Laboratory

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1. INTRODUCTION

The NASA Glenn Research Center (GRC) recently constructed an acoustical testing laboratory for use in supporting the noise control needs of the International Space Station (ISS) project. In support of the acoustical measurements conducted in the NASA GRC Acoustical Testing Laboratory (ATL) a quality system, designed in accordance with the requirements of ISO 17025, "General Requirements for the Competence of Calibration and Testing Laboratories", was been developed by JGS Consulting under contract to NASA GRC. This quality system currently supports sound power level determinations in accordance with ISO 3744, "Determination of sound power levels of noise sources using sound pressure — Engineering method in an essentially free field over a reflecting plane". The quality system is currently being expanded to include NASA procedures for verification of sound pressure level emissions of space flight hardware. This paper provides background information on the facility and an overview of the quality system that was developed to support the laboratory operations.

2. QUALITY SYSTEMS

ISO 8404 (1994) defines the term quality to mean the "Totality of characteristics of an entity that bear on its ability to satisfy stated or implied needs". An integration of this more formal definition of quality into the statement of objectives of for a testing laboratory might be that "The work performed in the laboratory will be done accurately, thoroughly and in accordance with established procedures, the first time". A quality system is a series of documented policies and procedures that guide the daily activities of a laboratory to ensure that these objectives are achieved.

The generally accepted standard for quality systems in a test laboratory is ISO 17025 "General requirements for the competence of calibration and testing laboratories". ISO 17025 was adopted in 2000 and replaced ISO Guide 25.

3. USING QUALITY SYSTEMS TO CREATE A LABORATORY ORGANIZATIONAL STRUCTURE

The quality systems requirements outlined in ISO 17025 provide an excellent set of instructions for creating the organizational structure for an acoustics laboratory. This is particularly useful when establishing a new laboratory, as personnel can use the standard to draw on the community of laboratory experience that went into the development of it as a reference document on high quality laboratory operations. It is also much easier and particularly useful to get quality systems practices established in a laboratory right from its inception. Much of the work that will eventually form the foundation for the laboratory's technical program (i.e. facility qualification, initial calibrations, test procedure development, etc.) is typically performed when a laboratory is first completed. However, since an overall laboratory organizational structure is often not created until later in the process, the documentation of this work is often lacking or not well integrated into laboratory documentation. If the quality systems requirements of ISO 17025 are applied to the laboratory from the time it is new, then some of the most critical technical work the laboratory performs will be well documented. In addition, laboratory personnel will more easily adopt quality system habits that will serve the long-term needs of the program.

4. THE NASA GRC ACOUSTICAL TESTING LABORATORY

The ATL was founded in 2000 to support low noise design of microgravity space flight hardware. The laboratory is used for the purpose of evaluating and controlling the noise emissions of experiment payloads on the International Space Station (ISS). These payloads are typically racks of fan cooled computer equipment that are designed to mounted onto the walls of the cylindrical space station modules. In order to address the noise control needs of the ISS, NASA Document SSP57000 on "Requirements for ISS Flight Hardware" contains requirements for the sound pressure level emissions from flight hardware and requires the determination of sound power levels of systems that exceed certain criteria levels. The NASA GRC ATL was designed to support measurement of noise emissions from flight hardware for system design, noise control and flight certification.

The NASA GRC ATL consists of a 21' x 17' x 17' (interior working dimensions) anechoic chamber that is convertible from a fully anechoic to a hemi-anechoic test environment. For most flight hardware noise emission evaluations the chamber is used in the hemi-anechoic configuration. An interior view of the ATL hemi-anechoic chamber and sound power level determination measurement surface is shown in Figure 1. As part of the initial evaluation of the test environment, qualification measurements in accordance with the requirements of both ISO 3745 and ISO 3744 were conducted. For the engineering grade, comparison method based sound power level determinations implemented by the ATL under this quality system, the chamber and measurement surfaces utilized have been documented to fully comply with the requirements of ISO 3744 Annex A in each 1/3 octave band over the frequency range of 63 Hz to 10 kHz. The documentation of these qualification measurements forms a foundation for the ATL sound power level determination technical program and quality system.

The ATL acoustic measurement system provides measurement capability for 10 channels of simultaneous real time proportional octave band and FFT measurements. This allows for quick sound power level determinations on sources that may be difficult to operate in a simulated mode for extended periods of time. The system uses Bruel and Kjaer microphones and signal conditioning to provide the inputs to a National Instruments based data acquisition hardware. The data acquisition system is operated via National Instruments Sound Power System software, a LabView based application that has been "source-code customized" by Nelson Acoustical Engineering. The NAE customizations address the specific measurement and quality systems needs of the ATL program.

5. QUALITY SYSTEMS AT NASA GLENN RESEARCH CENTER

The NASA Glenn Research Center (GRC) maintains an ISO 9000 compliant quality system that covers all work performed at the Center. When the ATL was established, GRC management desired to develop a quality system that was compliant with ISO 17025. This allowed for accreditation of the test facility by national standards bodies and ensured that the laboratory was technically competent when measured by the most current quality standards. Development of an ISO 17025 quality system for the ATL required GRC and ATL laboratory management to develop policies and procedures that go beyond what was available from the existing GRC ISO 9000 program.

While the quality systems requirements of ISO 9000 and ISO 17025 are similar in many ways, there are key differences between these two quality standards. The ISO 9000 series quality standards outline requirements for documentation of the basic administrative policies and procedures performed by ALL areas of the organization. By contrast ISO 17025 quality systems outline requirements for documentation of both the administrative and TECHNICAL policies and procedures in just the laboratory operations or the organization. They key distinction between ISO 9000 series quality standards and the requirements of ISO 17025 are the technical competence requirements of 17025. Therefore, an ISO 17025 quality system in a laboratory will satisfy the administrative requirements of an ISO 9000 series quality program. However, a laboratory that satisfies the organizations ISO 9000 quality program does not necessarily have a quality program that is ISO 17025 compliant. The similarities and differences between ISO 9000 and ISO 17025 are illustrated in Figure 2.

Therefore, the objective of the GRC management and the ATL staff was to integrate the existing GRC ISO 9000 quality system policies into an overall quality system for the laboratory and to develop the additional technical policies and procedures that would result in an ISO 17025 compliant quality system.

6. THE NASA GRC ATL QUALITY MANUAL

The ATL quality system is defined in the ATL Quality Manual, which outlines the general policies, procedures and organizational structure for ATL operations. This Quality Manual also makes reference to a number of other notebooks, files and support materials that comprise the complete quality system. The quality manual outlines the ATL policies in the following areas:

A. Quality Policy Statement

The ATL Quality Manual contains a Quality Policy Statement by NASA Glenn Research Center management stating its commitment to quality work in the ATL. This quality policy statement incorporates the GRC ISO 9000 quality policy statement and provides additional guidance to ATL employees of the quality standards supported by laboratory management.

B. Management Mandate/Personnel Commitment to Quality

The ATL Quality Manual contains a mandate from GRC management to the ATL Laboratory Manager to establish and maintain a quality system in compliance with the requirements of ISO 17025. This mandate provides both the responsibility to develop, and authority to implement and enforce, the ATL quality system. ATL Personnel are required to understand the quality system in detail and sign a statement of their commitment to maintain compliance with its documented policies and procedures.

C. Document and Documentation Control Procedures

The ATL Document Control Program defines the overall organizational structure for the laboratory. The ATL quality system currently consists of 12 notebooks and a series of physical and electronic files. The Document Control program outlines the overall structure for maintaining laboratory documentation and creates a logical place for the laboratory to organize its test files, quality system documentation and quality assurance documentation.

D. Policies on Confidential Client Information

The ATL plans to make its services available to outside testing clients and therefore needs to develop policies and procedures for protecting the confidential information of its clients. Information concerning test conducted for NASA and ISS contractors is handled in accordance with existing NASA procedures for confidentiality and information flow.

E. Policies on Internal Review and Independent Audit

The ATL quality system defines regular review and audit activities designed to assure that the ATL quality system stays up to date and that ATL activities are in compliance with its defined quality procedures. An annual internal review by ATL management assures that all policies and test procedures are updated on a regular basis. Audits by NASA GRC ISO 9000 audit teams, technical experts and NVLAP auditors assure that the quality system is being independently evaluated for both completeness and compliance.

F. Complaint Handling Procedures

The ATL quality system defines a set of procedures to be followed in the event a complaint against the laboratory's test results or compliance with its quality system is called into question by one of its clients. These procedures are designed to insure all valid complaints are fully investigated and the corrective actions needed to address deficiencies in the ATL quality system are addressed.

G. Procedures for Handling Departures

The ATL quality system can only define policies and procedures that will serve the needs of the laboratory in a majority of the situations it may encounter. However, the quality system defined and documented by the ATL is not the only way to address the requirements outlined in 17025 or the test standard being conducted. In some cases, there may be other methods different than those outlined by the ATL quality system that would address the requirements of these standards. In such cases, the ATL defines a procedure for granting and documenting departures for the policies and procedures outline in its quality system at the time the test was conducted. The benefit of having a documented quality system is that the ATL and its clients can assume that all work conducted in the laboratory incorporates by reference, all of the material documented in the laboratory quality program, unless a departure from these procedures is specifically documented in the test file.

7. QUALITY ASSURANCE PROGRAM DESIGN

The ATL Quality Assurance Program has been designed to ensure that each test method utilized by the ATL remains within established control limits. The Quality Assurance Program defines a set laboratory programs that support each test method and defines how the laboratory will prevent or address errors, if they occur. Key elements of the Quality Assurance Program defined by the ATL include the following.

A. Equipment Calibration and Maintenance Program

The ATL equipment calibration program is designed to work in conjunction with the NASA GRC Calibration Laboratory to insure that all equipment used in the ATL is calibrated in a manner that insures traceability of all measurements to the National Institute of Standards and Technology with known uncertainty. An Equipment Maintenance Program, along with a series of internal checks insures that equipment remains in calibration.

B. Documented and Validated Test Procedures

Each ATL test method has a written test procedure. The test procedure and all associated facilities, data acquisitions and analysis have been thoroughly checked and validated to be in full compliance with the standard.

C. Preventive Action Program

Each ATL test procedure has a set of defined intermediate checks that insure that any potential calibration drift, equipment malfunction or test procedure errors are detected before they can affect test results.

D. Personnel Training Program

All ATL personnel receive documented training on the quality system and technical procedures documented by the laboratory. Initial training, ongoing training and remedial training activities are defined and implemented by the ATL.

E. Proficiency/Repeatability Testing Program

The ATL maintains a calibrated Reference Sound Source (RSS) that is used to monitor the repeatability of its sound power level determination program. Laboratory established norms and control limits on the apparent sound power of this RSS allow the laboratory to detect drift and ensure that each test procedure maintains under control. The use of this reference standard, along with audited verification of laboratory personnel against documented test procedures, provide a system for verifying the proficiency of laboratory personnel authorized to perform testing. This program also provides valuable information on both the repeatability and reproducibility of sound power level determinations made by the ATL for use in its Measurement Uncertainty Estimation Program.

F. Independent Audit and Management Review

The ATL ensures compliance with its quality system and technical procedures by subjecting itself to regular independent audits by quality system and technical experts. Results of these audits are reviewed by NASA GRC management who have stated their commitment to maintaining a quality system that is fully compliant with ISO 17025.

These quality system activities are “wrapped around” each of the ATL test methods. Provided the test procedure and quality assurance activities remain with established control limits, the ATL test procedures allow it to conduct acoustical measurements with known repeatability and reproducibility. In the event that any non-conformance (i.e. error, omission, problem, malfunction, etc.) is detected, ATL has a defined process for determining the Root Cause of the non-conformance and for making Corrective Actions to one or more of the quality system processes outlined above. The ATL Quality Assurance Program is outlined in general and on a philosophical basis in the laboratory Quality Manual. Quality Assurance procedures for each test method are outlined in the Technical Handbooks that support each test method. A process flow chart of the ATL Quality Assurance program as described above is shown in Figure 3.

8. ATL QUALITY ASSURANCE ACTIVITIES

The ATL Quality Assurance Program defines a series of periodic quality assurance activities. These activities are designed to establish laboratory norms for use in test procedures and provide data for use in the ATL uncertainty model. The activities that have been defined by the ATL for its ISO 3744 sound power level determination program are as follows:

A. Ambient Noise Level Monitoring

Ambient noise levels in the ATL host building are monitored over extended periods of time and with varying levels of activity in and around the host site. In addition, the noise floor of the ATL measurement system was studied under various input conditions. Statistical studies of these levels have allowed the ATL to establish norms and maximum level conditions for its measurement system. Data from these studies are incorporated as Preventive Actions into the ATL test procedure.

B. Transducer Sensitivity Monitoring

The sensitivity of each of the ATL microphones are monitored and tracked. Since the ATL noise emission measurement systems are based around multi-channel data acquisitions, the ATL manages a fairly large number of microphones. Therefore, the ATL Transducer Sensitivity Monitoring program begins with careful documentation of each microphone/preamplifier assembly, tracking each by serial number as a matched pair. Upon return from external calibration, the calibrated sensitivity is reconciled with the local norms for calibration sensitivity by accounting for losses in preamps, signal conditioning and cabling. Local norms are established by calibrating each microphone repeatedly over a period of time in the ATL and statistical tracking of the apparent sensitivity of the transducer. Data from these studies are incorporated into a control chart and used a Preventive Action into the ATL daily calibration procedure. The data is also used in the ATL Measurement Uncertainty Estimate to estimate the magnitude of short-term calibration drift in the measurement system.

C. Sound Power Level Repeatability and K2 Control

The ATL maintains a Bruel and Kjaer Reference Sound Source as its primary reference standard for sound power level determinations. As part of its quality assurance and uncertainty estimation programs, the ATL tracks the locally measured sound power level of this reference sound source over time. Since the ATL sound power level determination program is fundamentally a comparison based, this data is used to generate control ranges for the K2 corrections (as defined by ISO 3744) applied to the surface averaged sound pressure levels. Norms and a control range for K2 values at each 1/3-octave band are established using statistical analysis methods and incorporated into the ATL test procedure as a Preventive Action. This program also provides fundamental information for use in the ATL Measurement Uncertainty Estimate.

Data for these periodic Quality Assurance Activities is generated on a daily basis as the ATL performs measurements and conducts it normal work. Studies and statistical analysis of the data is conducted quarterly and documented in the ATL Quality Assurance notebooks established for each program. This will allow the ATL to maintain documentation of these key measurement parameters from its inception and throughout its history.

9. USING SOFTWARE APPLICATIONS IN QUALITY SYSTEM DESIGN

The ATL quality system takes advantage of the software it uses to control its data acquisition devices and conduct its data analysis. The National Instruments Sound Power System software was designed to support laboratories that that maintain quality systems. In addition, several custom features were added to the source code of this software that facilitate the application of quality systems processes to tests conducted using it. The software provides built in tools for calibration control of multiple microphones. This allows the ATL to establish norms for the calibration sensitivities of its transducers and test engineers can use the built in control charting capabilities to quickly visibly verify that their measurement system calibrates within laboratory norms. Test Documentation modules allow the ATL to record all information associated with the test article and test conditions needed to ensure that results can be properly reported and repeated.

Custom modifications to the National Instruments Sound Power System source code by Nelson Acoustical Engineering (NAE) added additional quality controls to the ATL measurement program. A Reference Spectrum

features allows the ATL to track ambient and system noise levels against established norms, allowing the facility to quickly determine that neither acoustic or instrumentation noise levels interfere with measurements. A Noise Intrusion Alarm feature monitors an 11th microphone, located outside of the test chamber, at the same time the ten measurement microphones located inside of the chamber are sampled. The sound pressure levels on microphone 11 are adjusted by the known airborne noise reduction properties of the anechoic chamber and the software will generate an alarm if any event occurs during the acquisition that may interfere with the measurement.

Each of these software features are integrated into the ATL test procedure and Quality Assurance Program. These software features allows the ATL to easily maintain very detailed monitoring of the parameters it has identified as being key components of measurement uncertainty and to prevent sources of measurement error before they can affect test results. Figure 4 shows a screens shot of the Sound Power System software with the NAE modifications.

10. ASSESSMENT AND ACCREDITATION OF THE ATL QUALITY SYSTEM

In February of 2002, the ATL submitted its quality system and ISO 3744 sound power level determination program for assessment by the National Institute of Standards and Technology, National Voluntary Laboratory Accreditation Program (NVLAP).

11. IMPLEMENTATION AND EXPANSION OF THE ATL QUALITY SYSTEM

This paper has focused on the design and documentation of the initial quality system at the NASA GRC ATL. However, a quality system is not as much defined by its design and initial documentation as it is for implementation by laboratory personnel and for its evolution over time. The ATL quality system defines within itself a process by which it will be constantly changed and updated through a process of periodic internal reviews and independent audits. The quality assurance program defines a process designed to detect and correct non-conformances, thereby defining a process whereby the laboratory learns and improves as a part of its day-to-day operation. The challenge for the ATL staff as they take this program into the future is to implement the quality system it has defined, improve the quality of the measurements it conducts and expand the quality system to cover other activities within the laboratory.

12. TAKING QUALITY SYSTEMS AT NASA GRC AND THE ATL INTO THE FUTURE

The ATL NVLAP accreditation currently only applies to its ISO 3744 sound power level determination program and ISO 17025 quality system, since NVLAP accreditation is based on defined scope of measurements. However, the ATL strives to use and benefit from its quality system procedures in all of the work that it conducts and intends to expand the quality system to cover additional measurement procedures conducted in the laboratory. The ATL goal for 2003-2004 calls for full integration of the NASA SSP57000 procedure for measurement of noise emissions from spaceflight hardware into the quality system and for the addition of additional measurement surfaces to the existing ISO 3744 sound power level determination program. In addition, NASA GRC management has found the process of implementing an ISO 17025 quality system in one of its test laboratories to be a beneficial organizational experience and is currently studying the merits of implementing similar quality systems in other GRC laboratories.

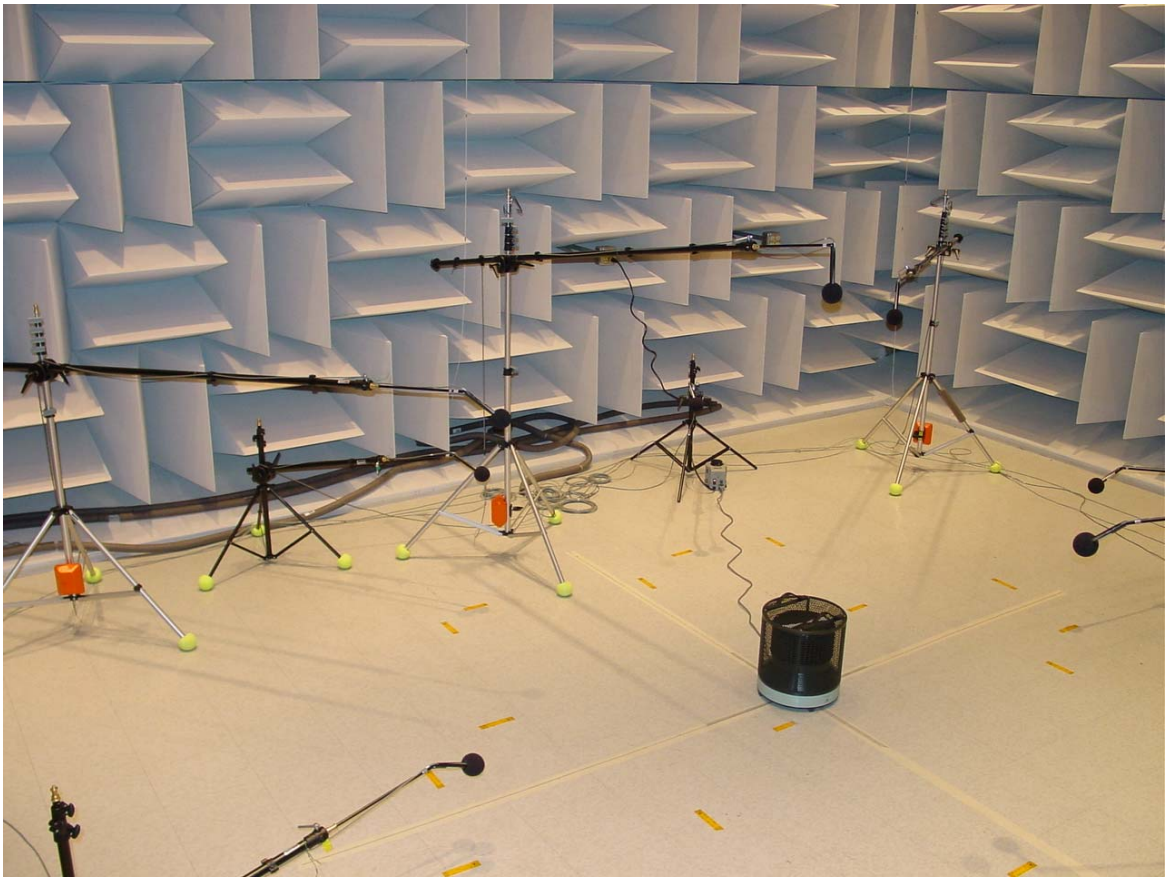

Figure 1 – Interior of NASA GRC Acoustical Testing Laboratory (ATL) chamber in hemi-anechoic configuration with Reference Sound Source at typical specimen location. Markings on floor assist with microphone positioning.

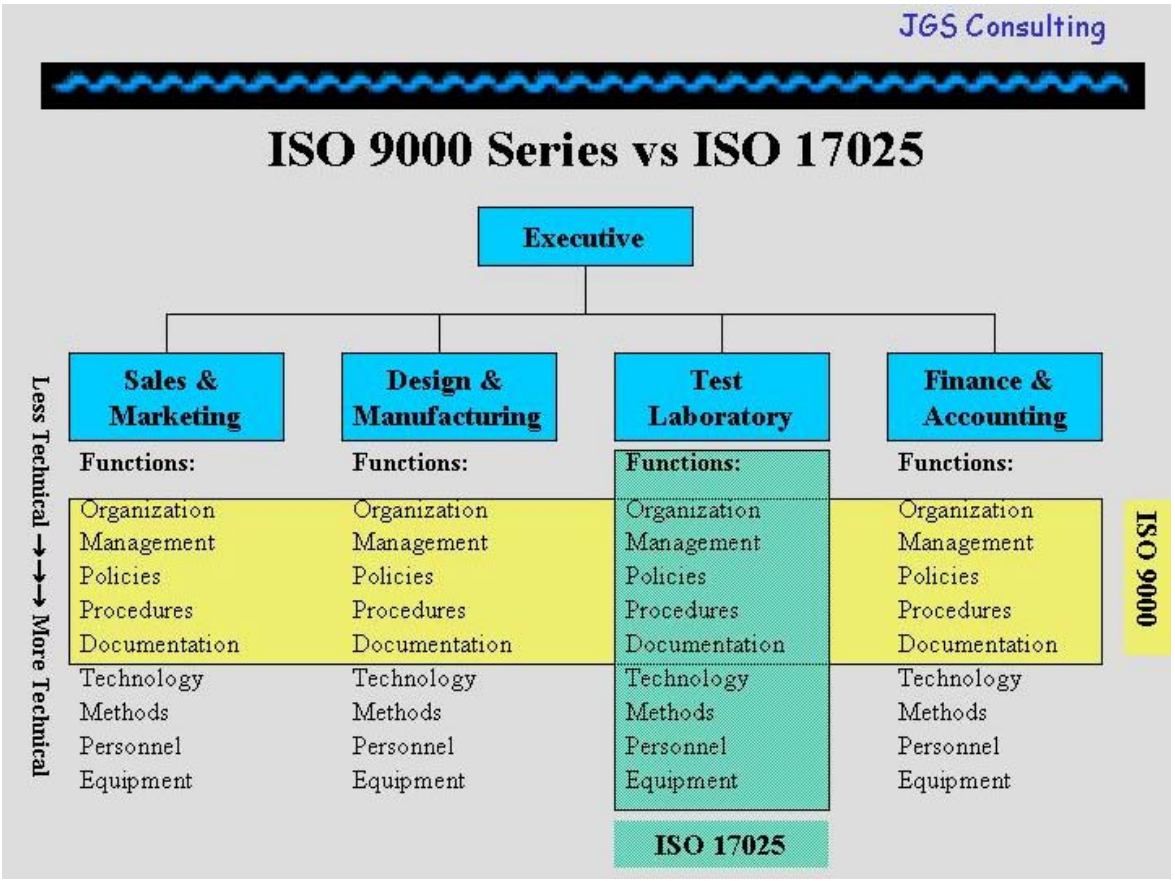

Figure 2 – Comparison of ISO 9000 versus ISO 17025 Quality System Requirements as it relates to a typical organization with a test laboratory.

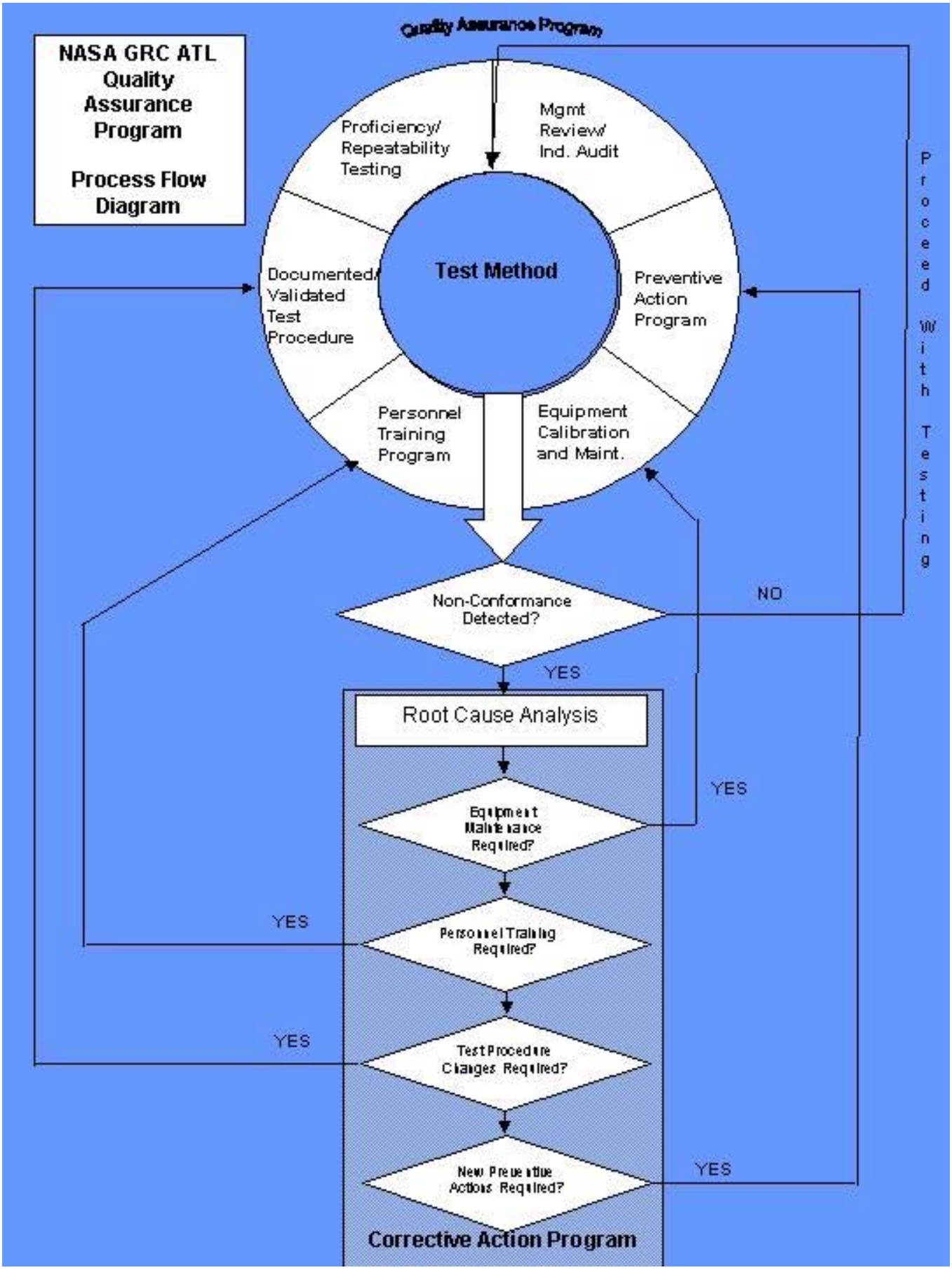

Figure 3 – ATL Quality Assurance Program Process Flow Diagram

Figure 4 – Screen shot from multi-channel real time analysis display of ATL custom data acquisition system software. Noise Intrusion Alarm indicator shows bands which may have been affected by external noise during the acquisition.