In-flight Modified Rhyme Tests (MRT) for PA System Qualification in a Large Aircraft

Gopal P. Mathur[*1], Manny Tsangarakis[2], David J. Lotts[2], Kenneth R. Barry[2] and Naval Agarwal[3]

The Boeing Company
[1]5301 Bolsa Ave., MC: H013-B308, Huntington Beach, CA 92647 USA
[2] 2401 E. Wardlow Road, MC: C052-0066, Long Beach, CA 90807 USA
[3] 700 S. Renton Village Pl, MC: 6M6-31, Renton, WA 98055 USA
gopal.p.mathur@boeing.com (e-mail address of lead author)

Abstract

This paper will present results of in flight investigations conducted in a large military aircraft with high background noise levels. Speech intelligibility in varying noise environment and with a moving speaker was evaluated in this aircraft. MRT measurements were conducted to evaluate performance and qualification of new analog/digital PA systems. In these tests, emphasis was placed on "relative" measurements between different system configurations and these results will be presented in this paper. The MRT was found to be most reliable method for the PA system qualifications when performed according to ANSI standards. Use of aalternative analytical methods for speech intelligibility as a replacement for MRT is also discussed.

INTRODUCTION

The military aircraft test and evaluation community generally uses the Modified Rhyme Test (MRT) method for evaluating speech intelligibility of the communication system. The MRT is conducted in the critical mission areas per Millitary, ANSI and/or ISO specifications. These standards specify that the MRT shall be conducted in a noise field that simulates the actual aircraft noise at the measurement location. Since the MRT method is based on the perception of words by listeners, it places no limitations on the characteristics of the sound system or the environment. Modern communication systems, however, incorporate several new electronic designs, e.g., automatic gain control, Analog-To-Digital (ADC) conversions that can introduce non-linearity in the system. These digital new systems

are generally non-linear and acoustic feedback between PA system speakers and moving announcer microphone can interfere with the MRT. The main objective of this work was to evaluate and conduct in-flight MRT and compare it with analytical methods to evaluate a new PA system in a large aircraft. Also, analytical approaches for PA system performance qualification that can be used in place of the currently specified MRT are examined.

SPEECH INTELLIGIBILITY: ANALYTICAL AND TESTING METHODS

Various analytical methods to determine speech intelligibility can be grouped as follows: Speech Transmission Index (STI), Rapid (or room) Acoustic Speech Transmission Index (RASTI), Phonetically-Balanced word scores (PB), Modified Rhyme Test (MRT), Speech Intelligibility Index (SII) - also known as Articulation Index (AI), and Articulation Loss of consonants (%ALcons). A brief description of the measurement and/or calculation approach of each method is given in Table 1. The references/standards for each method are also given in the first column of Table 1.

Table 1. Speech Intelligibility Measurement/Calculation Approach

Method	Approach
STI (IEC 60268-16)	Synthesized speech test signal. SI calculated from measurement of signal modulation depth through a channel for each of 7 octave bands and 14 modulation frequencies
RASTI (IEC 60268-16)	Simplified STI method using fewer octave bands and modulation frequencies
PB (ISO/TR 4870-1991)	Talker speech input. Transmission of specifically-chosen word set to a panel of listeners. SI calculated from listeners' recordings of % correct words
MRT (ANSI S3.2-1982)	Talker speech input. Transmission of specifically-chosen word set from a known population to a panel of listeners. SI calculated from listeners' % correct words recorded
SII (AI) (ASA S3.5-1998 Supersedes ANSI S3.5-1969)	Synthesized noise test signal input. Measurement of speech signal sound pressure levels (S) and ambient noise (N) at given set of frequencies. SI calculated from a weighted average of S/N for up to 20 frequency bands in the speech spectrum
%ALcons (J. Aud. Eng. Soc. 1971)	Talker speech input. Transmission of specifically-chosen consonant word set to a panel of listeners. SI calculated from listeners' % correct words recorded

Parameters that Impact PA Speech Intelligibility

The following parameters affect the PA system speech intelligibility: input signal characteristics (e.g., paragraph, sentence structure, and word type), PA subsystem signal amplification and distortion, Signal to (background) Noise Ratio (SNR) and signal frequency bandwidth at the listener position, analysis of signal frequency bandwidth, and number of frequency bands used. The reverberation due to room enclosure or other equipment, environmental affects, such as, pressure and humidity and hearing protection are also important parameters. The limitations of each method are given in Table 2.

Table 2. Limitations of Measurement/Calculation Methods Related to Speech Intelligibility

Method	Limitations
STI	Synthesized test signal input. Transmission should be linear with amplitude compression limited to 1 db. No Conversion of speech into digital signals
RASTI	Leads to erroneous results in the presence of a reverberant environment due to fewer frequency bands modulations used
PB	Single consonant words tested. Significant training
MRT	Single consonant words tested. Vocabulary public. Test can be tuned a priori
SII (AI)	Pink noise input
%ALcons	Word limitation leads to erroneous results in the presence of a reverberant environment

Speech Intelligibility Index (SII) Testing Method

In this method, wideband pink noise signal is sent through the transmission channel and the output of the system is analyzed at various positions. SII requires linearity in system performance without digital coding and wideband ambient noise. After initial SII is computed, the result is derated for such factors as reverberation, narrow band noise, hearing protection, etc. Reverberation is measured separately for use in the SII calculations.

Assessment of SII Testing Method

SII (also known as Articulation Index, AI) represents an analytical method for predicting the performance of a PA system and should be used with listener tests[1].

There is a variance in test results of typically .02 due to the random nature of the pink noise. It is also influenced by such factors as temperature, humidity and pressure. Speed of sound changes in different environmental conditions causing microphones located in the same position to be exposed to different sound pressure levels. Human listeners may adjust head positions to optimize position for better hearing. Calculated results generally are worse than listener assessment[2].

Speech Transmission Index (STI) Testing Method

Modulated wideband pink noise sinusoidal signal is sent through the transmission channel. A transmission index is calculated at specific octave bands and scores are added up to provide STI. STI includes reverberation and distortion caused by chamber. STI requires linearity in system performance without digital coding and includes wideband ambient noise. Results have to be re-assessed if a hearing protection device is used[2].

Assessment of STI Testing Method

STI represents an analytical method for predicting the performance of a PA system and should be used with listener tests[1]. There is a variance in test results of typically .02 due to the nature of the signal. Test conditions such as reverberation and distortion are included in the calculated results. This is an improvement over the SII method. Calculated result may be worse than listener assessment[2].

FLIGHT TESTS

Current qualification approach for a PA system in a large aircraft is to conduct the Modified Rhyme Test and achieve MRT score of 77% or higher. Both pilot/co-pilot and crew/passenger positions were required to pass the MRT in flight. The test aircraft is shown in Figure 1.

MRT Test Method

During MRT conducted in the test aircraft, crew went through standard briefings and asked listeners if they understood the briefings. Crew then asked specific listeners to do specific tasks. “Listener located at a location/station, stand and raise your right hand.” MRT testing needs to be conducted under similar environmental conditions. Control of humidity, pressure/altitude and temperature is necessary, but some variation is acceptable. Talker spoke 50 words into sound reinforcement system in the ambient noise environment required for the test conditions. Listeners selected the word they believe is spoken from a list of six. Scores were corrected for guessing – higher MRT scores have less of a correction factor

Figure 1. Test aircraft.

The repeatability and predictability for speaker/listener testing can be improved by the following specific keys: (1) native English talkers and listeners with no accent, (2) auditory normal – proven via a hearing test, no occlusions in ear canal. The training for listeners is also important that they should have heard all the talkers speak and the test material. Depending on the verification approach, testing could be a few hours to several hours over several days. Before the testing, the listeners need to be 'soaked' in the noise environment for at least 30 minutes. First test of the day is not scored. Additionally, listeners that operate in the noise environment consistently demonstrate better performance when tested as long as the above criteria have been met.

The following options can be used as preparation for the in-flight testing in a 'Live' environment: (1) test may be recorded, (2) conduct test using a pre-recorded speaker (3) record in the ambient noise environment. However, one will not be able to 'couple' ambient noise into talker's microphone. The audio output of recorded speech need to be matched with output of microphone of the talker and also recorded speech will need to use aircraft PA system microphone. Ambient noise and pre-recorded speech can be mixed in the chamber and listeners score off the recorded audio. Listeners scored off the mixed recording using a pre-recorded speaker on the ground and mixing with the ambient noise.

DISCUSSION

For repeatability of tests, it was necessary to conduct the test under similar environmental conditions, e.g., humidity, pressure and temperature. Test results are impacted by both speaker and listener performance. When training and methodical approaches are applied, test results are consistent within an acceptable tolerance, i.e, repeatable within +/- 1.5%. At least 5 speakers and 10 listeners are required to reduce an individual's impact on the overall performance. Also, previously discussed criteria

were rigorously applied to reduce variability and increase predictability in the current tests.

Two analytical methods, SII and STI, were also examined. Based on current analysis and previous MRT scores, an STI in the range of 0.25 to 0.35 was expected. STI is more comprehensive than SII, since it accounts for distortion and reverberation, however, STI is only applicable to analog, linear systems. If any digital solution is implemented, speaker/listener testing is recommended. Several software tools used yielded different results, therefore the main concerns are the need to use a software tool that gives consistent results. The results indicate that there is need to conduct STI tests prior to MRT. Results variability need to be accounted before making a recommendation as incorrect results results could understate performance of system.

Ambient noise in the test aircraft at a specified passenger seat location is shown in Figure 2. The voice output levels at the speaker locations should be higher than the ambient noise levels at receiver locations. The redesigned analog PA system with a moving speaker was qualified after the in-flight MRT tests.

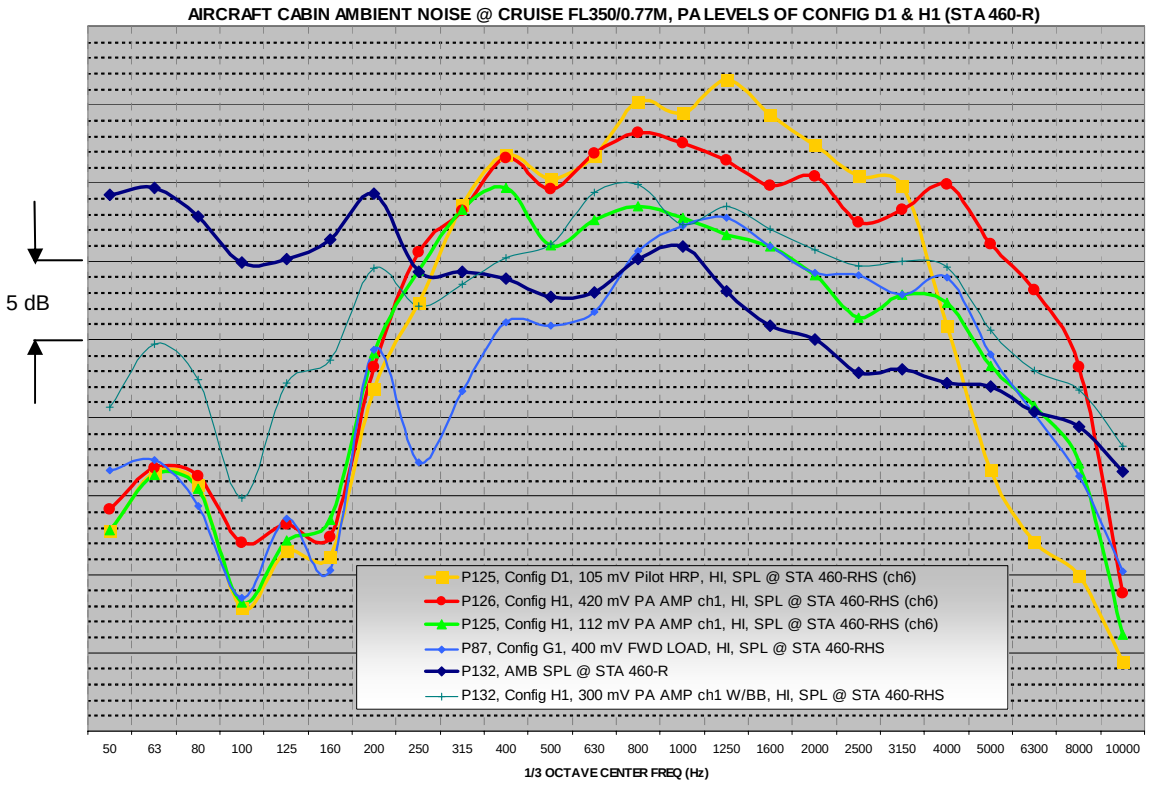

Figure 2. In-flight ambient noise.

CONCLUSIONS

In-flight MRT (Modified Rhyme Test) for qualification of a new PA system were conducted in a large aircraft. There were technical challenges in meeting MRT requirements with a digital, non-linear PA system. Acoustic feedback between the moving speaker microphone and loudspeakers also hampered MRT. Reverting to an analog PA system helped to pass the MRT requirements. Standard ANSI specifications must be followed in conducting in-flight MRT for PA system qualification. Other analytical methods such as SII (Speech Intelligibility Index) and STI (Speech Transmission Index) for use as a qualification test were examined. Analytical methods are applicable to linear, analog systems. STI may be used for analog, linear PA systems during design and development to reduce cost and cycle time.

REFERENCES

1. International Standard, IEC 60268-16- STI Sound system equipment – Part 16: Objective rating of speech intelligibility by speech transmission index. (2003-05).

2. E. Bowden, J. Rathsam and L. Wang, “A verification of computer modeling predictions of speech intelligibility,” Paper presented at the 148th meeting of the Acoustical Society of America, San Diego, CA, Nov. 2004.