NASA Handbook 7010: Direct Field Acoustic Testing

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ABSTRACT

Instruments, spacecraft, antennas, reflectors, and other mechanical hardware have been undergoing acoustic qualification testing over the last decade using loudspeakers. This speaker-generated Direct Field Acoustic Test (DFAT) method offers cost, mobility, and schedule advantages over the conventional Reverberant Acoustic Field Test (RAFT) method. To develop most appropriate acoustic test program using the DFAT method for a flight project, flight project managers and their technical staffs will need overall guidance and technical rational for using DFAT to qualify flight hardware for acoustic environments. The NASA Chief Engineer Office had tasked JPL to prepare a NASA Handbook for DFAT Dynamics Testing. The handbook was completed and was released by NASA headquarters in 2015. The handbook provides advantages and disadvantages of such method of testing, key references and a series of recommended practices for test preparation and test performance. This paper will summarize key and important steps related to this method of acoustic testing.

KEY WORDS: Reverberant acoustic field, direct acoustic field, speakers, vibro-acoustic, acoustic/structural modal coupling, handbook

INTRODUCTION

In the early 1990's the NASA Office of Chief Engineer (OCE) implemented a program to develop NASA-wide standards to provide NASA handbooks to encourage the use of best practices and to support consistent application of engineering issues across the Agency. So far several handbooks on different disciplines have been published and made available for all NASA flight hardware projects. These handbooks are being occasionally updated to reflect advances in the technology.

The direct field acoustic testing (DFAT) handbook is a new standard prepared on a relatively new acoustic testing method. The 7010 Handbook was published by the NASA in 2015 as a guidance document to provide engineering information; lessons learned; possible options to address technical issues; classification of similar items, materials, or processes; interpretative direction and techniques; and any other type of guidance information that may help the NASA or its contractors in the design, construction, selection, management, support, or operation of systems, products, processes, or services.

DFAT has certain advantages over the conventional RAFT approach, in particular, reduced facilities development and maintenance costs and portability of the acoustic test equipment. Significant advances in the DFAT control systems have been made in the last few years, which alleviate many of the previous concerns with this test method. However, application of DFAT varies widely among the NASA Centers and their contractors. Therefore, this Handbook provides the best current guidelines for implementation of the DFAT test method.

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The structural responses induced by direct field testing often differ significantly from those induced by diffuse field testing, usually at specific frequencies or a range of frequencies. One of the parameters that strongly influence structural responses is the acoustic standing wave coupling with the structural modes. Many references are provided in the handbook and a few are cited here[1-3].

Many of the earlier DFAT tests perform on qualifying flight hardware for acoustic launch environments used the single input single output (SISO) control system to control the sound pressures within the DFAT set volume. This method of controlling the acoustic field is discussed in some detail by Larkin and Goldstein[4]. However, a series of development tests performed at JPL indicated significant differences in the acoustic fields generated by the loudspeakers and reverberant acoustic fields[3] using SISO control system. The recent development and the application of multi input and multi output (MIMO) acoustic control applied to DFAT testing provide much improved methodology over the SISO control system.[5-7] Even though, the MIMO control system helps to reduce the interference patterns, therefore, non-uniformity of sound pressure within the testing volume, the existence of the acoustic standing waves and their impacts on the structural responses should be evaluated prior to qualification of flight hardware.

The purpose of this Handbook is to provide information and guidelines on the applicability and use of DFAT testing. This Handbook is intended to provide an approach which may be consistently followed by those who choose to use this method for qualifying flight hardware for acoustic environments. The Handbook describes the following:

- **a.** DFAT testing background.
- **b.** Configuration.
- **c.** Instrumentation, test control, and data acquisition and reduction.
- **d.** Theoretical considerations for designing a DFAT test setup.
- **e.** Examples discussing the pros and cons of this method of testing.

The information provided in the handbook is intended to guide engineers and engineering managers in making more informed decisions in the planning and execution of DFAT test activities. Additionally, the fundamental basis is provided for the development of procedures to facilitate execution of the DFAT testing process based on standards and recommendations developed in the past decade.

DFAT SOUND GENERATION EQUIPMENT

The specific equipment to be used for each test is determined by the dimensions of the test article, shape and level of the target acoustic specifications, facility layout, and any unique aspects of the test. For example, limited footprint availability, overhead obstructions, other test equipment present, and workflow traffic patterns need to be taken into consideration when planning a test. A DFAT system can be customized to address most requirements. Section 5 of the handbook discusses sound generation sources such as loudspeakers, woofers, and horns. The basic system components consist of a set of commercial speakers, stereo power amplifiers, and a control system (for more details refer to Larkin and Goldstein[4]). This section of the handbook provides

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information for the users to make themselves familiarize with the type of equipment and control system that are required to generate sound pressure levels using DFAT.

INSTRUMENTATION, DATA PROCESSING, AND CONTROL SYSTEMS

The instrumentation, data processing and control systems used for DFAT testing are very important portion of this method. In general, free-field omni-directional type microphones are used for sound pressure measurements. Microphones should be selected, positioned, and oriented with protection of the test article in mind and to meet the intended acoustic requirement. In all cases, instrumentation should be selected with the proper sensitivity and frequency response range required for the test. To do this, the background noise and maximum test SPL should be known and the corresponding transducer output should be matched to the selected signal conditioner.

The sound pressures are stored as time histories and processed in real time into the frequency domain. In addition, the data is stored as PSDs and/or n^{th} octave SPLs. The time history data can be reprocessed using different averaging, windowing, blocking, etc. to see the effect on the resulting spectrum. It is recommended that the data from at least one microphone be acquired by an independent system for verification purposes. Control for the direct field environment can be provided by most typical acoustic control schemes. Narrowband and constant bandwidth, closed-loop, digital controllers are preferred. An adequate number of control microphones are to be positioned circumferentially around the test article at elevations obtained using analytical predictions. They should be placed no closer than 0.6 m (2 ft) from the test article surface and no closer than 0.9m (3 ft) from the speakers. It is also recommended that an additional reference microphone and a microphone array also be used to further characterize and document the sound field. These microphones can be moved around during the pre-test checkout to help fully characterize the sound field and to re-position control microphones and increase the number, if needed, to better control the acoustic field. The goal is to understand the variations within the sound field and to tune for optimum uniformity by minimizing the constructive and destructive interference of sound waves within the testing volume. Details of the SISO and MIMO control systems are discussed in Section 6 of the handbook.

TEST SETUP AND CHECKOUT PROCEDURES

Various arrangements of speaker cabinets can be used depending on the desired results. A basic configuration for exposing a generic test article on all sides to a specified acoustic environment is to place the test article on a stand, or suspend it from an overhead cable, at least 3 ft above the floor and surround it with stacks of loudspeakers. Control microphones are to be placed at least 2 ft away from the surface of the test article and at least 3 ft away from the front face of the loudspeakers. This is to minimize the influence of test article surface effects and near-field effects from individual loudspeaker units on the control microphone measurements. Outer limits on the distance of loudspeakers from the test article are determined analytically. More details on equipment layout, power required for speakers and data acquisition system, microphone calibration, mass mock up setup, flight hardware test startup, low-level sound field with flight hardware, test duration segmentation are provided in Section 7 of the handbook.

GUIDELINES FOR DFAT TESTING

It has been shown, even with the advancement of the control systems, using DFAT for acoustic qualification testing, the pressure field and measured structural responses can differ significantly

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from an RAFT test, even if the control microphones are kept within the test tolerances specified. Because of the non-uniformity that may exist in the acoustic field generated by DFAT testing, care is to be taken when performing this type of test to have sufficient instrumentation on the test article to prevent exceeding hardware capability as the test level is increased and have an adequate number of microphones in place during the test to monitor the pressure field generated near critical items. It should also be noted that variability in the acoustic field generated by a DFAT test may result in under-testing as well as over-testing in specific frequency bands, and all efforts are to be made to map the acoustic field relative to acoustically sensitive hardware to ensure that an adequate test can be achieved and the intended requirements can be met.

The following guidelines are recommended for DFAT to address some of these technical issues:

a. Pre-test Preparation

(1) Before exposing the flight hardware to DFAT-generated acoustic field, model the acoustic field with and without the hardware using analytical and numerical tools discussed in the Handbook. The modeling results may provide useful knowledge about the acoustic standing waves and interference patterns within the testing volume. The pre-test analysis may also help optimize the location of the loudspeakers and control microphones to produce the most optimal acoustic field applicable to a specific spacecraft or other test article and will help identify empty DFAT volume fundamental acoustic modes below a few hundred Hz. The results also provide structural modes of the test article at low frequencies that may be susceptible to the acoustic standing pressure excitation. This exercise may also help orient/position the test article in the DFAT volume to minimize acoustic modal coupling impact.

(2) Use the results from step (a. (1)) to design DFAT with locations of the speakers and the hardware to come up with an optimal configuration to help lower the impact of the acoustic standing and interference wave patterns. The minimum space between speakers and the test specimen is to be no less than 1.5m (5 ft).

(3) The modeling efforts in step (a. (1)) may help to identify the locations and number of microphones to be used in the test setup that yields the optimal acoustic field within the testing volume. A minimum of 16 control microphones spread throughout the testing volume and in critical locations are to be used to control the SPLs and these ARE NOT to be used to tailor a specified requirement (i.e., acoustic pressure limiting is not recommended). An additional eight microphones are recommended to be used for the verification of the sound field. The recommended fixed locations for these verification microphones are to be equally spaced around the circumference of a circle 0.6m (2 ft) radially from and mid-elevation of the test article.

b. DFAT Test Setup Preparation

(1) The DFAT setup is to be designed with the information obtained from pre-test analysis. A simple mock-up test article and an acoustic array are required to map out the pressure field within the DFAT volume. The sound pressure variation within the test volume is to be identified using the microphone array and be minimized as much as practical below several hundred Hz (refer to Sections 7.6 and 8.5 of the Handbook).

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A. The microphones shall be positioned around the test hardware within the DFAT volume at sufficient distances from all surfaces to minimize absorption and re-radiation effects. A distance from any surface of at least ¼ of the wavelength of the lowest frequency of interest is recommended.
B. In facilities where this distance cannot be achieved, the microphones shall be located at least ¼ of wavelength from any acoustically responsive surfaces (5 ft discussed above provides ~100 Hz lower frequency).

(2) The acoustic field near the top of the speakers' stacks exposed to the room should be measured and characterized. Steps are required to produce more uniform acoustic field if acoustically responsive surfaces, such as reflectors and panels, are located near the top of the DFAT speakers stack. This is the region where the acoustic energy egresses from the test volume, and may result in a lower SPL. If the SPL is too low at the top of the stack, speakers may need to be placed overhead or tilted. Conversely, if there is a big reflecting surface or cavity above the test item, i.e., the facility ceiling, there may be a standing wave resulting in higher pressure at the top of the test item.

(3) The SPLs from each control microphone are not to deviate by more than +/-3 dB from the specification input SPLs.

(4) Perform an acoustic test with a mock up test article and thoroughly examine the structural/acoustic modal coupling at lower frequencies and acoustic field within the speaker circle.

c. Flight Hardware Test Setup Preparation

(1) Once steps (b. (1)) to (b.(4)) are completed and reviewed by dynamics engineers, the testing may continue with flight hardware. Perform a low-level acoustic test with the hardware and thoroughly examine the structural/acoustic modal coupling at lower frequencies.

(2) Re-orient test hardware in the DFAT volume, if necessary, to minimize coupling effects; i.e., move sensitive components away from pressure nodes/velocity anti-nodes of the coupled frequencies. For example, the test item may need to be raised to minimize the impact of low-frequency pressure doubling near the floor of the DFAT volume.

(3) Examine low-level data (both sound pressure and acceleration/strain responses) by extrapolating to the full level (0 dB) acoustic level and proceed if no structural issues are anticipated due to coupling.

(4) For large test hardware, where re-orientation may not be possible, use additional instrumentation to better gauge the coupling issue.

In Section 8 of the Handbook attention was given to the DFAT test setup design and acoustic field characterizations using analytical models, acoustic standing waves and interference patterns, impact of acoustic standing waves on structural responses, speaker test layout design using FEM/BEM, and control and monitor microphones layout.

One of the important contributors to the non-uniform acoustic fields is related to the acoustic standing waves and interference patterns. It has been demonstrated that the structure and acoustic mode coupling can result in an un-anticipated overtest for some low mass to area structures like antennas, solar arrays, etc.[1-3] Recently, the reverberant chamber acoustic/structural coupling phenomenon was demonstrated by tailoring an aluminum panel to couple with two chamber

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modes. The results from this activity, as discussed in some detail by Kolaini and O'Connell[2] and Kolaini, Doty, and Chang[3], convey an important finding related to the coupling phenomenon. The standing waves are prevalent in a DFAT setting and typical standing waves modes are in the frequency range where most spacecraft components have resonance frequencies and must addressed either through testing and/or analysis.

Another important topics discussed in the Handbook is to predict the spatial characteristics of the sound field generated by a DFAT test as it interacts with a given test article. The pre-test analysis will provide invaluable information for test planning. Perhaps the most suitable modeling tool for predicting sound-structure interaction is BEM analysis or a hybrid combination of BEM and FEM. Some progress has recently been made in the development of capabilities applicable to modeling DFAT testing using BEM method[8,9].

SUMMARY

A new handbook on discussing standard practices for using the DFAT acoustic testing was completed by the author and was released by NASA headquarters in spring of 2015 as a guidance document. This handbook provides engineering information, lessons learned, possible options to address technical issues, classification of similar items, materials, or processes, interpretative direction and techniques, and any other type of guidance information that may help the NASA centers or its contractors in the design, construction, selection, management, support, or operation of systems, products, processes, or services.

A series of guidelines are provided in the handbook and are briefly discussed in this paper. The control microphone placement is critical to a successful DFAT test because of the known variance in the sound field. The inclusion of more control microphones randomly placed within the testing volume to obtain the control average is critical to narrow the spatial variations. Strong emphasize is given to pre-test preparation and modeling. The important phenomenon that may result in structural failure is the acoustic standing waves coupling with the structural modes. An assessment of such coupling is recommended to be performed through BEM/FEM analysis.

ACKNOWLEGEMENT

The author would like to thank David Oberhettinger of the JAPL's Office of Chief Engineer and Paul Gill of the NASA's office standard for funding to prepare this handbook. This work was carried out at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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BIOGRAPHY

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