GER-1108

a program for

MISSILE VIBRATION CONTROL

through environmental testing

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G-E designed missile — the Hermes A-1 — was launched in 1950.

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Effects of environmental vibration must be considered for a successful missile. Carefully planned tests will help engineers determine environmental and vibration specifications, choose compatible systems and put vibration resistance into components.

A Program for MISSILE VIBRATION CONTROL Through Environmental Testing

For high missile reliability and performance, the designer must have and apply vibration environmental data at the appropriate stages of development, design, testing and maintenance of missile components and systems. Briefly, the essential steps for a vibration program are as follows.

1) Determine the vibration environment by monitoring vibrations at their sources and learn from analysis and test those other natural frequencies that are difficult to change locally.
2) Consider vibration effects during the preliminary design study phase, which determines the choice of the propulsion, guidance, control and structures systems.
3) Consider vibration effects during the design of components.
4) Qualitatively determine and achieve the vibration factor of safety through development vibration testing and accompanying redesign.
5) Maintain quality with the minimum of production vibration tests, which should uncover flaws without appreciably reducing the life expectancy of the components.

• Vibration Environment

The most important part of any program is knowledge of the vibration environment in which the missile works. An ideal would be to have precise information about the frequencies and amplitudes of the vibrations at every component within the missile.

For most missiles, the three chief sources of vibration excitation are from the aerodynamic loads, propulsion system, and ground handling and transportation.

The characteristics of the various responses of the missile and its components influence the choice of the means for determining the contributions of the sources to the vibration environment and suggest the remedial action when necessary.

Aerodynamic Excitation Responses. The missile responds to a sudden maneuver or gust load by a damped vibration, which is some combination of the missile's natural flexural and torsional modes at their associated frequencies

Propulsion Excitation Responses. The missile structure responds to the oscillating forces imposed by the propulsion system by vibrating at the same frequencies with associated amplitudes. Because of energy losses induced by structural damping, the response is likely to be of a smaller magnitude than the source, except for local resonances.

Handling or Transit Source Responses. The responses of the structure to transit excitations are the same as that for a gust loading or for an oscillating force, depending on whether or not the excitation is periodic. The type and amplitude of the transit excitation is random. Much statistical data on transportation vibration and shock does exist and are published. However, the inclusion of these transit considerations in a missile design would be imposing

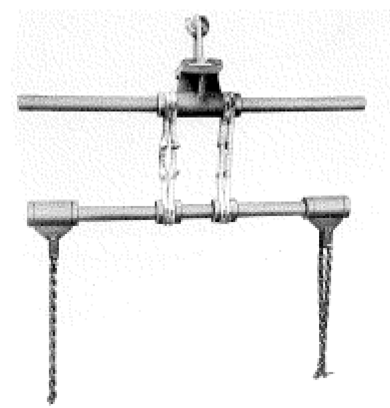


Figure 1. Suspending the missile from elastic shock cords provides the free-free boundary condition that allows excitation of the free-free modes.

an unwarranted penalty upon the missile whose main purpose is to fly reliably. A suggested solution is to make provision in the missile container for shock and vibration damping and isolation to reduce the amplitudes of the transit environment to an acceptable level.

• Vibration Environment Program

At the beginning of a missile development program, there exists no exact information regarding the nature of the vibration environment. Instead, assumptions based on past experience are made. Specifications may only be in the form of vibration amplitudes over broad frequency ranges and include no specific frequency data.

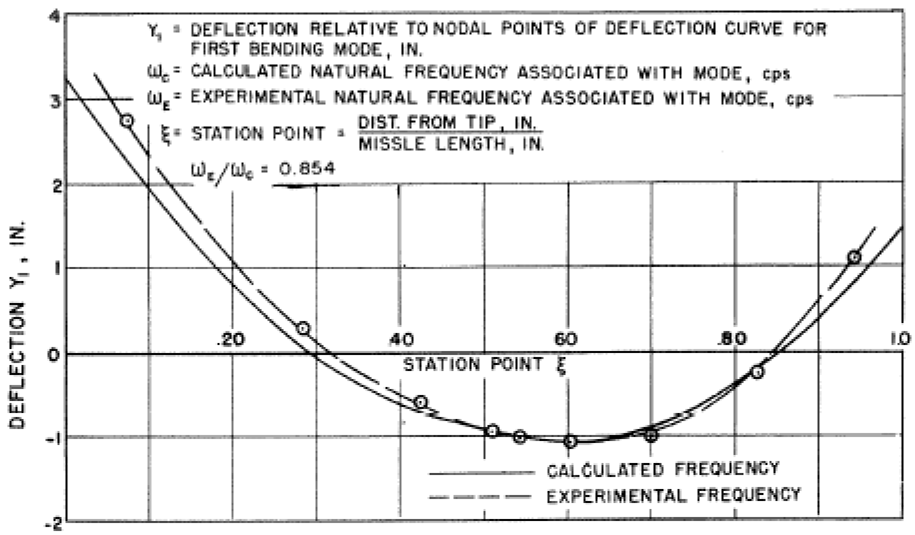


Figure 2. First bending mode of a given missile.

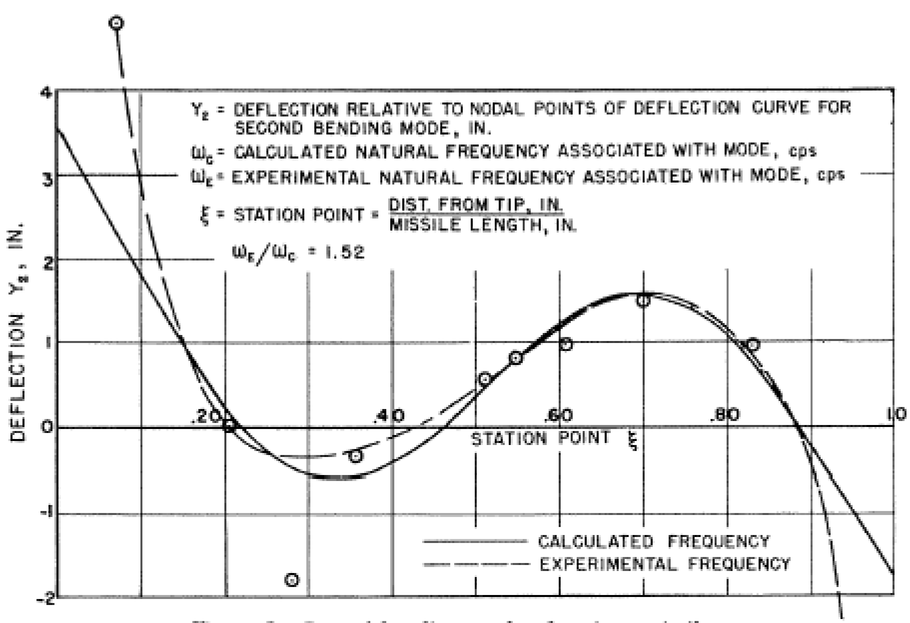


Figure 3. Second bending mode of a given missile.

Vibration Control

For natural vibrations, quantitative frequency data may be had before fabrication. The natural frequencies and flexural modes of vibration of the missile structure may be determined with fair accuracy by analytical means. The analysis requires that stiffness and mass distributions be known. Fairly large changes in the mass and its distribution have a relatively small effect on the analytical results.

The missile structure transfer function can be found and included in the missile servomechanism analysis. There are other analyses, such as the torsional natural frequencies of a similar and of a more local nature that can be performed during the initial design stages.

• Measure Vibration Amplitudes and Frequencies

When the missile frame is constructed, the missile structural bending modes, associated frequencies, transfer functions, and structural damping can be

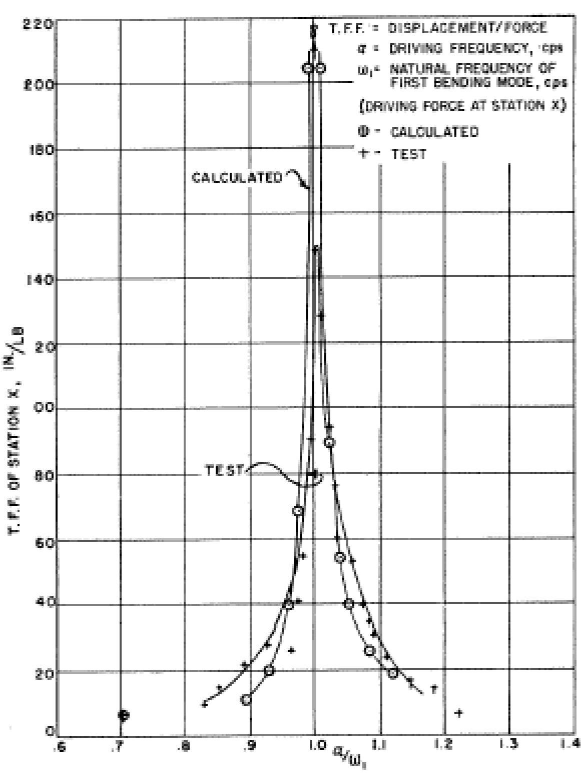


Figure 4. Transfer function T.F.F.

found from a test on an actual airframe. In the test, the airframe should be loaded to have a simulated total mass and distribution identical with the actual missile. It may be suspended horizontally from elastic shock chords which effectively supply the free-flight free-free boundary conditions, as shown in Figure 1. The response of the frame to sinusoidal force inputs can be noted and it is possible to find the natural frequencies and mode shapes. Structural damping may be had from decay and frequency response curves. For instance, Figures 2 and 3 compare the calculated with test curves of the flexural mode shapes as obtained for a particular missile. A transfer function as determined analytically is represented by the solid lines in Figure 4 while the dotted lines are the same transfer function found by test. With such natural frequency data available in the very early stages of development of the missile, it is possible to help insure compatibility of the airframe with its guidance, control, and propulsion systems.

Prior to the time a missile flies or is even constructed, static hot runs of the propulsion system are usually made. Vibration measurements of source points taken during these runs help to make the environmental data complete. Later, when a complete missile structure and system is given a static hot test, more accurate amplitude as well as frequency data are obtained.

In each instance, experience indicates that the amplitude of vibration, especially during the start-up or shut-down transient period, correlates very well with actual flight conditions; and except for low frequencies, there is good correspondence with actual flight frequencies. Test hot runs of the propulsion system provide a means for obtaining early frequency data.

Finally, telemetered vibration data from flight tests serve to complete the vibration environmental picture. With all the data compiled on a single graph, it becomes possible to determine an envelope describing the maximum values of acceleration encountered over the range of frequencies present.

Vibration Control

• Vibration Specifications

The vibration specification (derived from the environmental data), which components must satisfy, should be under constant adjustment. Initial specifications drawn from past experience should be continuously altered by adding data obtained from analyses, propulsion tests, and missile static tests. With the addition of flight environmental data, it can be complete and finalized.

• Vibration Consideration in Product Design

The most important factor affecting the success of a component design with respect to vibration is a realization by the engineer that this equipment will be operating in a severe vibration environment. The specific details of construction of this item are governed in a large measure by the philosophy that this completed equipment must operate successfully in the vibration environment solidly mounted to the missile structure, that is, without shock and vibration isolation. It is apparent that the development engineer must choose parts that in themselves are not weak links. This requires the use of ruggedized tubes and other parts that individually meet the vibration specifications.

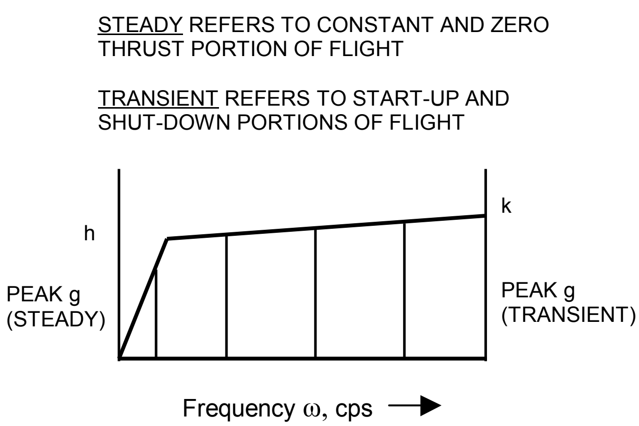


Figure 5. – Amplitudes of vibration experienced, throughout the missile at various frequencies are enclosed in the envelope.

• Environmental Testing

The role of development testing is to discover weaknesses owed to design and mounting techniques and eliminate these weaknesses. The vibration tests are conducted upon the entire unit mounted to a table with the actual missile bracket; the test is not conducted upon some part of the components. Testing the entire assembly assures the designer that the problems arising during testing will be those encountered in the missile rather than those arising from the peculiar method of mounting a particular part of a component.

Some parts of the vibration specification, because of their transient nature, cannot be easily simulated in the laboratory. It was noted that the vibrations during the static hot runs of propulsion and missile systems simulate to a greater accuracy the actual flight environment than any other testing mechanism. Therefore, the propulsion system of the missile during a static hot run constitutes an ideal test bed for a final examination of the developed products. If the developed components operate successfully mounted to the propulsion system test bed during a hot run, this will justify feeling confident that it will prove reliable in flight.

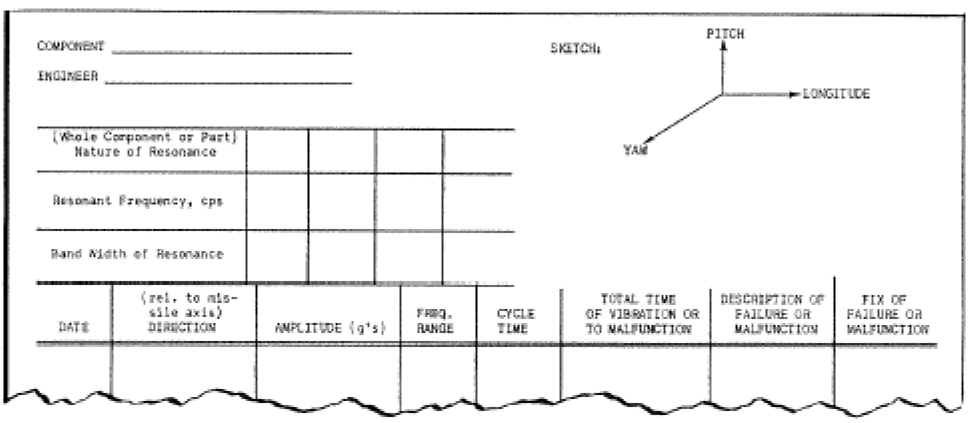
In the past, much valuable information has literally been thrown away. A large number of components and systems have passed through the development test phase without leaving a cohesive, orderly, and meaningful record of their progress. This is probably true of all environmental type tests and certainly for vibration tests.

If an appropriate record of the history of the vibration tests is maintained, then several advantages are obvious. It will be possible to ascertain in some measure the reliability of components relative to each other, their possible life expectancy, and the overall reliability of a system of components. In addition, it may be possible to note patterns or items of relative weakness. Should an operation failure of a component occur, the record may help to pinpoint the cause of such malfunction with some saving of time likely. In order that the records be cohesive and orderly and susceptible to correlation, a uniform vibration testing procedure must be established and a uniform record kept. A suitable record form is shown on Figure 6.

• Conclusions

The procedures for minimizing the effects of vibration which have been discussed are by no means complete. In general they are salient ones necessary to the vibration program, which in its abbreviated form is:

1) Determine the environmental and vibration specification.
2) Choose compatible systems.
3) Design vibration resistance into components.
4) Test and re-design to remove vibration flaws.
5) Use a minimum vibration test for quality maintenance.



COMPONENT ______________________

ENGINEER ______________________

SKETCH:

(Whole Component or Part) Nature of Resonance				
Resonant Frequency, cps				
Band Width of Resonance				

DATE	(rel. to missile axis) DIRECTION	AMPLITUDE (g's)	FREQ. RANGE	CYCLE TIME	TOTAL TIME OF VIBRATION OR TO MALFUNCTION	DESCRIPTION OF FAILURE OR MALFUNCTION	FIX OF FAILURE OR MALFUNCTION

Figure 6. Suggested record form for testing results.

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